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ECONOMIC ANALYSIS HANDBOOK THEORY AND APPLICATION

VOLUME II. CONCEPTS AND TECHNIQUES

GENERAL RESEARCH CORP.

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This four-volume handbook is designed as a practical guide for preparers and reviewers of Army economic analysis studies. The goal is to facilitate improved analyses which will lead to better decisions and use of Army resources.

Economic analysis in the context of this handbook is concerned with the costs and benefits of alternative ways of accomplishing a particular task. The handbook is intended for analysis of investment

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projects yet to be finally approved or disapproved. It is not intended to provide insights on the best way to justify prior decisions on investment projects.

Volume I serves as the general introduction to the subject of economic analysis. It covers the major steps involved in an economic analysis study and provides brief descriptions of the origins and current status of economic analysis within the Army.

Volume II is designed for the preparers of economic analysis studies. The steps, concepts, and procedures of economic analysis are described in detail and illustrated by examples.

Volume III is written for reviewers of economic analyses. It is presented in terms of a series of key questions addressing such matters as assumptions, methodology, formulation of alternatives, and presentation of results.

Volume IV provides two case studies of actual Army economic analyses. Each case study describes and evaluates the pertinent analyses and presents a catalog of lessons learned. The case studies helped shape the content and extent of attention given to various subjects in Vols I to III and provided illustrative examples.

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ECONOMIC ANALYSIS HANDBOOK
THEORY AND APPLICATION

Volume II—Concepts and Techniques

by

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PREFACE

This document is one of four volumes constituting the Army Economic Analysis Handbook. The other volumes are Vol I, "Army Investment Analysis," Vol III, "Guide for Reviewers of Economic Analysis," Vol IV, "Case Studies."

The project within General Research Corporation was performed under the direction of Mr. Albert D. Tholen, Director, Resource Analysis Department, and under the management of Mr. Walter H. Bennett. A significant contribution was made by Mr. Richard Zabell in App A, Mr. Paul Palatt in App B, and Mr. Brent Bowen in App D.

This work, the exposition of economic concepts and their relationship to analysis applications, was strengthened immeasurably by the technical contributions of Dr. T. Arthur Smith, Assistant Comptroller of the Army for Economic Policy and International Programs. Dr. Smith has directed graduate seminars in cost-benefit analysis for several years at The American University. This background, supported in turn by his experience as Chairman, Defense Economic Analysis Council, and as Chairman of a Defense Department Automated Data Systems Evaluation Committee were heavily utilized in establishing structural guidance for the content of these four volumes.

The Study Advisory Group members also provided valuable support and technical guidance. They are Mr. Robert Verbeke, Office of the Comptroller of the Army; Mr. George Antle, Office of the Chief of Engineers, Institute for Water Resources; MAJ Craig Hagen and LTC Joseph H. Schwar, Jr., Office of the Assistant Vice Chief of Staff, Management Information Systems.

SUMMARY

PURPOSE

The Economic Analysis Handbook is designed as a practical guide for preparers and reviewers of Army economic analysis studies. The immediate goal is to facilitate improved analyses, but the ultimate justification is the premise that improved analyses will lead to better decisions on and use of Army resources.

OBJECTIVES

The primary objectives of the Handbook are to:

- State the purposes, uses, and limitations of economic analysis.
- Provide guidelines for planning an economic analysis.
- Provide comprehensive coverage of essential economic analysis concepts and procedures.
- Supplement the limited coverage in other areas with references to additional sources.
- Establish standards for economic analysis presentation and documentation.
- Provide guidelines for reviewers of economic analyses.
- Present lessons learned from case studies of real-life Army economic analyses.

SCOPE

Economic analysis in the context of this handbook is concerned with the costs and benefits of alternative ways of accomplishing a particular task. Thus, for example, the analysis focuses on the "most economic" way to build a heliport. It does not investigate resource requirements

and capabilities for a single approach to heliport construction. Nor does it address the merits of building the heliport as opposed to carrying out a different task, for example, improving messing facilities. The single approach problem falls within the province of the budget analyst, while the problem of assessing new heliports vs improved messing facilities is the responsibility of high-level decision makers.

Economic analysis is applicable to a wide range of activities involving proposed acquisition of goods and services for Army use. The handbook is intended for analyses of investment projects yet to be finally approved or disapproved. It is not intended to provide insights on the best way to justify prior decisions on investment projects.

ORGANIZATION

The handbook is organzied into four volumes. Volume I serves as the general introduction to the subject of economic analysis. It covers the major steps involved in an economic analysis study and provides brief descriptions of the origins and current status of economic analysis within the Army.

This volume is designed for the preparers of economic analysis studies. The steps, concepts, and procedures of economic analysis are described in detail and illustrated by examples.

Volume III is written for reviewers of economic analyses. It is presented in terms of a series of key questions addressing such matters as assumptions, methodology, formulation of alternatives, and presentation of results.

Volume IV provides two case studies of actual Army economic analyses. Each case study describes and evaluates the pertinent analyses and presents a catalog of lessons learned. The case studies helped shape the content and extent of attention given to various subjects in Vols I to III and provided illustrative examples.

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1 INTRODUCTION

PURPOSE

This volume addresses concepts, theory, and techniques applicable to economic analysis. The main body represents a selective reordering of Volume I, with additional details supplied as necessary. More specifically, the procedural orientation of Volume I has been replaced by a presentation organized around major concepts—for example, costs, benefits, uncertainty. The appendixes provide more specific details which are illustrated by some of the important techniques associated with the disciplines of economics, financial management, mathematics, and statistics. In this volume concepts and techniques are illustrated, where possible, by use of examples taken from actual analyses.

WHY ECONOMIC ANALYSIS?

At all decision-making levels of society—the individual, the family, the private firm, the various Governmental organizations—decisions are made to allocate resources to either present activities or future activities. These decisions are influenced to varying degrees by economic considerations and by noneconomic factors such as habit, standing operating procedures (SOPs), and politics.

The purpose of economic analysis is to provide the analyst and the decision maker with a formalized, disciplined, and standardized approach to identifying and summarizing the economic considerations of a problem involving choice among alternatives. The procedure for performing an economic analysis is to assess the alternatives in terms of costs and benefits, and to present the findings in an orderly manner for use in decision making. This facilitates the making and reviewing of decisions by:

a. Focusing informal thinking.

b. Surfacing hidden assumptions, making clear their logical implications.

c. Providing an effective vehicle for communicating the considerations which support a recommendation.[1]

Planning, Programming and Budgeting System (PPBS)

The Army's economic analysis program is a major component of the Planning, Programming, and Budgeting System (PPBS) of the Department of Defense (DOD).

The Planning, Programming and Budgeting System (PPBS) was instituted by the Government in 1965 in order that every Federal agency might better:[2,3,4]

- Articulate our national goals with greater precision and on a continuing basis.
- Choose from among these goals those that are most urgent.
- Search for alternative means of reaching our goals most effectively.
- Inform ourselves not merely on next year's costs, but on the second, third, and subsequent years' cost of our programs.
- Improve the measurement of program performance to insure that a dollar's worth of service is given for each dollar spent.[2]

The PPBS provides both the framework and the means of recording decisions regarding DOD resource utilization. Ultimately, many decisions are based on economic analysis, and as a result of this important role in the decision making process economic analysis is referenced in prevailing DOD guidance[5] as an integral part of the PPBS.

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[1] Dept of Defense, "Economic Analysis Handbook," 2nd Edition, undated.

[2] Mark Alfandary-Alexander, editor, Analysis for Planning, Programming, Budgeting, Washington Operations Research Council, Washington, D.C., 1968.

[3] Murray L. Weidenbaum, "Planning-Programming-Budgeting Systems: Selected Case Materials," Washington University, St. Louis, Missouri, 1969.

[4] Fremont J. Lyden and Ernest G. Miller, editors, Planning, Programming, Budgeting: A System Approach to Management, Markham Publishing Company, Chicago, 1968.

[5] Dept of Defense, "Economic Analysis and Program Evaluation for Resource Management," DODI 7041.3, 18 Oct 72.

Applications

Economic analysis provides the basis for decision making with respect to the application of resources in alternative systems or projects. In performing an economic analysis, the outputs (benefits) of each alternative must be measured as well as its utilization of resources (costs). In order to adequately measure and assess all benefits and costs, due consideration must be given to the qualitative factors as well as the quantitative factors. In cases where qualitative factors cannot be reduced to measurable units, they should be described verbally and included in the documentation of the quantitative analysis.

Economic analysis may be described as future oriented because it addresses the use of resources in the future rather than in the past. The purpose is to assess future alternatives for resource applications, not to justify decisions already made. The future-orientation of economic analysis does not rule out its application to current programs, although it does make the justifications and past expenditures for such programs irrelevant. As such, the current mode of operation will often be included as one of the alternatives in an economic analysis. Potential applications include the following:

- Choice of alternative proposed programs
- Proposed programs vs current program
- A current program vs other current programs (possible elimination of duplication)
- Reevaluation of programs in development to confirm or deny further development.

The focal point of economic analysis is decision making and selection of alternative courses of action. Relative cost and benefit among alternatives are the criteria for selection, and the precise measurement of absolute cost and benefit are secondary to the analysis. J. P. Large summarizes this viewpoint that the basic purpose of analysis is "to provide estimates of the comparative or relative costs (and benefits) of competing systems, not to forecast precisely accurate costs suitable for budget administration. In this context consistency of method is just as important, perhaps more so, as accuracy in some absolute sense."[6]

[6] J. P. Large, "Introduction" in Concepts and Procedures of Cost Analysis, RM-3589-PR, The RAND Corporation, Jun 63.

The recently issued DODI 7041.3[5], while affirming the importance of economic analysis in planning and programming, strongly emphasizes its importance to budgeting, indicating that "project officers and managers should be prepared to demonstrate the cost effectiveness of budget proposals and to submit detailed analyses in support of budget estimates." Where an economic analysis has been used in helping make a budget decision, the submitted analysis should provide requisite documentation. As described earlier, justification fabricated after a decision has been made must not be confused with economic analysis.

Limitations

An appreciation of economic analysis involves a recognition of its limitations as well as an understanding of its potential applications, concepts, and techniques. It is easy to exaggerate the role that analysis can play in decision making. Perhaps the best way to counteract this is to list some of the things that analysis cannot do.

First, an economic analysis does not make any decision. Its sole purpose is to help the decision maker choose among alternatives. This is done by providing an orderly display of the costs and benefits of each alternative, the assumptions under which the calculations were made, and the nonquantifiable attributes of each alternative.

Second, an economic analysis seldom provides all the information necessary to make a decision. The tools of economic analysis are useful in establishing the economic considerations involved in the choice among alternatives, but provide for little other than narrative descriptions of such considerations as health, welfare, and morale. The decision maker must interpret the information provided by the analysis in this light, interject any additional information and considerations, make value judgments, and finally make a decision.

Third, an economic analysis ordinarily cannot identify an optimal alternative. Generally an analyst can only recommend the choice of a particular alternative over all other alternatives considered in the analysis. This does not mean that the analyst should passively accept the alternatives originally established. Often one of the best ways that the analyst can contribute to the investment in high-quality programs is to suggest viable new alternatives.

LANGUAGE OF ECONOMIC ANALYSIS

The language of economic analysis, to the extent that it differs from that of every day life, consists mainly of terms from the fields of accounting, economics, financial management, mathematics, and statistics. In order to establish a general framework for subsequent discussion, basic terms are defined here. Other terms, including those related to mathematical and statistical techniques, are defined in later chapters and/or appendixes.

Economic Life

The economic life of a project is the period of time over which the benefits from a project may reasonably be expected to accrue. Benefits from a project are limited ultimately by its physical life. This is the number of years a facility or piece of equipment will be available before it is used up in a physical sense, that is, decayed or deteriorated beyond economical repair. Physical life may vary significantly depending upon usage, such as a lathe used 24 hours a day vs 4 hours a day.

The economic life of a project is further limited by its technological life. This is the period before which improved technology makes a building, machine or process obsolete. Although equipment may have remaining physical life, it is sometimes economical to replace with more modern equipment.

The economic life of a project may be further limited by military or political considerations which may suggest benefit accrual for a much shorter period. In this case, mission and threats must be analyzed to determine the economic lives of proposed projects.

Economic life is a determinant of the number of years included in an economic analysis, often called the "analysis time frame." It is important to make the best possible determination of economic life in light of a project's physical and technological lives and associated military or political consideration.

Analysis Time Frame

Economic life determines the number of years included in an economic analysis. Determining the period of analysis for projects with identical economic lives is straightforward, e.g., equal to the economic life of the projects. However, the relation between analysis time frame and

economic life becomes less direct when such complexities as different economic lives for the alternatives, production/funding leadtimes, and fielding of alternative components enter into a problem. Existing guidance documents[5,7] address the first two complexities and suggest means of allowing for them in determining a proper time period. Section 2 provides details and also examines the implications of different time-phased fielding patterns of system components for total system economic life and analysis time frame.

Life Cycle Cost Analysis

Life cycle costing has been applied to military problems involving total force structures or specific weapon/support systems for at least the past 20 years—in the earlier years under the name "cradle-to-grave" costing. The guiding principle of life cycle cost analysis is that projects or systems potentially pass through three stages—research and development (R&D), investment, and operations.

The economic analysis format promulgated in AR 37-13[7] requires a project cost breakdown by year in terms of R&D, investment, and operations. In general terms, R&D costs precede the procurement of a system. Investment costs reflect the systems procurement and operating costs represent the systems recurring operation.

Life cycle costing has gained its wide acceptance because it provides a useful, comprehensive, and logical framework for developing and presenting costs. Section 3 illustrates these points and provides further discussion.

Benefit Analysis

The purpose of benefit analysis is to identify, measure, and evaluate the benefits of proposed alternatives with respect to one another. Where possible, benefits are quantified in terms of dollar value. Those benefits that cannot be assigned a dollar value often can be described in terms of effectiveness and expressed in units that indicate new or improved capability. Other benefits that cannot be meaningfully quantified should be described in narrative form.

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[7] Dept of Army, "Economic Analysis and Program Evaluation of Resource Management," AR 37-13, 6 Apr 73.

Uncertainty

The principles of classical economics are predicated on the assumption of perfect information. This implies that all alternative outcomes are known with certainty. In actuality, uncertainty is present in virtually all decision making activities. Economic analysis is no exception and as a result of its future orientation it is an activity with a high degree of uncertainty.

The analyst can reduce the level of uncertainty by searching for new information or generating additional information through carefully designed experiments. Within the practical limits of available resources, an attempt should be made to compensate for uncertainty. Even after all efforts have been made to reduce uncertainty, there will still be the problem of facing the remaining uncertainty. In brief, the analyst's task is to determine how to take uncertainty into account in calculating and presenting costs and benefits for the alternatives under consideration.

Section 5 discusses this problem further by addressing the issues of empirical analyses of uncertainty, the need for uncertainty analysis, approaches to uncertainty (a fortiori, contingency, sensitivity, statistical analysis), and documentation considerations. Appendixes B and D provide additional explanation, including examples of specific techniques for handling uncertainty.

2 ESTABLISHING THE ANALYSIS

BACKGROUND

The conduct of an economic analysis will depend on where in the Army decision hierarchy the need for the analysis was recognized, on the magnitude of the resources involved, and on the time available for completion. A completed study serves as an information document rather than a decision document. It is useful to the extent that it provides clear, meaningful, and unbiased estimates of costs and benefits of relevant alternatives.

The decision maker can be perceived as the customer of an economic analysis study and the analyst as the producer. These are convenient abstractions since they establish a hierarchy of functions, with the decision maker approving and using the results of the analysis and the analyst conducting and submitting it. The abstractions take on added meaning when viewed against the background of the decision maker/analyst relationship portrayed in Fig. 1. An individual, as indicated in the figure, may function as a decision maker (DM) on one level and analyst (AN) on another—just as at certain times he may act as customer and others as producer.

The present chapter discusses the conceptualization activities that precede major efforts of data gathering and calculation. The activities collectively are referred to here as "establishing the analysis" and include problem definition, establishment of objectives, formulation of assumptions, and specification of alternatives. Quality performance of the conceptualization phase is essential to the success of an analysis.

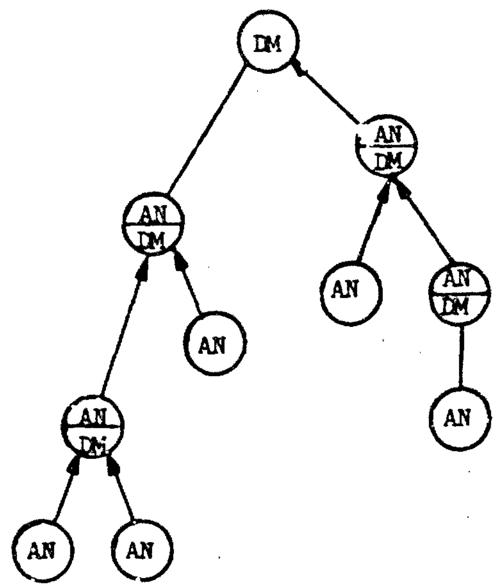

Fig. 1—The Decision Maker (DM)/Analyst (AN) Relationship

Estimation techniques applied to the right problem can sometimes provide useful results, even in the case of severe data limitations. However, no amount of care in data collection or sophistication in calculation can compensate for carelessness in problem formulation.

TASKING ORDER

A tasking order is a document that establishes the requirement for an economic analysis study. It is approved by a decision maker, submitted through the appropriate bureaucratic channels, accompanied by additional guidance prepared at successively lower decision levels, and ultimately forwarded to an analyst as part of a total instruction package. At a minimum, a tasking order should address the major objectives of the study and the resources, especially time, that can be devoted to conducting it.

The bureaucratic aspects are minimized where the decision maker and analyst have a close working relationship. In some cases the analyst may

participate in drafting the tasking order and documentation may be limited to a memorandum with brief statements of objectives and constraints. Study objectives and constraints can be clarified subsequently as the need arises.

Where a close working relationship does not obtain, the decision maker must rely primarily on the tasking order and scheduled in-process reviews (IPRs), if any, to help ensure that the economic analysis study is investigating the proper questions. To do this, the tasking order must present clearly the major study objectives, special guidance and constraints, and study time schedule.

Chapter 2 of the Comptroller of the Army (COA) Costing Methodology Handbook[8] suggests the types of guidance that should be provided to a cost analyst by a tasking organization. Although the suggested guidance is limited to that required for costing and envisions more detail than practicable for most economic analyses, many of the particulars cited would be welcome entries in economic analysis tasking orders. Examples include:

- Time allowed for preparation of analysis
- Quantities and/or proposed force structures
- Alternatives to be considered in the analysis
- Special sensitivity analyses to be performed
- Assumptions and general factors to be used in analysis
- Treatment of risk and uncertainty
- Specification of constraints (e.g., budgetary)

PROBLEM DEFINITION

An Army economic analysis simply does not happen. The need for an analysis is created when an element in the Army decision hierarchy perceives problems in the current ways of meeting a set of objectives and foresees possible opportunities for improvement. The analyst enters the picture when someone in authority approves the undertaking of the analysis and issues a tasking order.

[8] Dept of Army, Comptroller of the Army, "Costing Methodology Handbook," Apr 71.

Point of Departure

The tasking order provides a point of departure for the analyst. The first and, in many respects, most important function of the analyst is to extract the basic information from this source, add his own judgment and experience, and formulate an initial problem statement. The statement must be formulated in such a way that it will facilitate results pertinent to the decision maker and provide a suitable framework for conducting the analysis.

Impact on Analysis

The initial problem statement always should be viewed as working guidance to be revised and expanded in accordance with additional information. This in no way diminishes the importance of initial problem definition. An improper or a confusing statement prepared at the outset of the study may lead either to studying the wrong problem or to precluding considerations of worthy alternatives.

Limits on Problem Definition

There are practical limits on problem definition. Problem statements must encompass objectives that are consistent with the policies of the immediate and higher organizations and must be formulated so as to keep the study within manageable proportions. Nevertheless, there is considerable room for innovation on the part of the analyst in all but the simplest studies.

Inadequate Tasking Order

An analyst may become convinced that the tasking order does not address the real problem or addresses only one facet of a larger problem. In such cases the analyst either can attempt to subsume the implied problem statement under an expanded one or can attempt to resolve issues in question through communication with the decision maker. The latter course is attractive and practicable where the analyst and decision maker have a close working relationship.

OBJECTIVES

Objectives set minimum standards of performance, isolate critical processes and functions, and set forth relevant time frame considerations.

A list of objectives serves two distinct purposes. First, it acts as a screening device, removing from further consideration any proposed investments that do not meet the standards. Secondly, it provides a framework for developing viable alternatives and for measuring and relating their costs and benefits.

Relation to Problem Statement and Tasking Order

In establishing objectives the analyst must ensure that they relate to the problem addressed in the problem statement and not to a narrower one more readily analyzed. The analyst also must verify that all explicit or implied objectives in the tasking order are either incorporated as study objectives or demonstratively inappropriate. Failure to do so creates a strong risk of study disapproval and subsequent redo.

Functional Orientation

To the extent possible the objectives should address the "what" of a proposed investment rather than the "how." That is, they should be oriented to the desired functional outputs rather than to particular means of obtaining the outputs. The means are subjects for subsequent investigation and contribute to the specification of the alternatives considered in the analysis.

The analyst must keep in mind that the establishment of objectives and the specification of alternatives are conceptually two separate functions. The danger of telescoping these functions into a single step is that feasible alternatives may be overlooked. Typically those eliminated would tend to be the more innovative.

Use in Tracking

Analysts, particularly those working as proponents, must guard against over-optimism in setting of objectives. Objectives should be established with the view that they will be employed in measuring the success of a particular investment and the management of its implementation.[9] This means that the objectives set must be attainable given such factors as the investment time frame and state of technology.

[9] Dept of Army, Office of the Adjutant General, Ltr, subject: "Economic Analysis of Proposals Supported by Automated Data Systems," 27 Jan 72.

ASSUMPTIONS

Assumptions are made throughout the course of an economic analysis study. They are used in defining the study problem, in establishing the alternatives, in providing means for treating unknown or difficult to quantify elements, in performing calculations, and in reporting the study results. The analyst cannot perform a study without assumptions or provide a complete analysis without listing and justifying all major assumptions.

Types of Assumption

The guidance letter[9] on economic analysis for ADP systems divides assumptions into two classes—state-of-nature and mathematical. State-of-nature assumptions structure the bounds of the analysis, permit the analyst to construct alternatives, and, when explicitly presented in the analysis, permit the decision maker "to understand and question the construction of alternatives and the bounds within which they were considered."[9] Mathematical assumptions are used in structuring relationships, extrapolating trends, and establishing factor values.

This section discusses the state-of-nature assumptions. State-of-nature assumptions are broadly defined and can be subdivided according to several different criteria. The four types described below represent different dimensions of the state-of-nature—time, quantity, activity level, degree of support.

Time. Proper determination of the analysis time frame requires careful attention to several time-related assumptions. The basic assumptions are those of the economic lives of the alternatives and of their scheduled introduction into the Army inventory. The impact of these and other time-related assumptions on the analysis time frame are discussed in the following paragraphs.

Time considerations are simplest when:

- All alternatives have a common economic life.
- All alternatives are introduced as entities in "one year."
- Production/funding leadtimes are not of primary concern.

These conditions are satisfied in many, perhaps the great majority of economic analyses. Where the conditions hold, the number of years in the time frame is a direct function of the assumed economic life.

An example of a simple relation between economic life and analysis time frame is provided in a recent economic analysis[10] of a computer-assisted inspection and diagnostic system. This analysis, which is the prime focus of the case study appearing in Vol IV, addressed a proposed expansion of the Depot Multipurpose Automatic Inspection and Diagnostic System (DepotMAIDS) at the Letterkenny Army Depot (LEAD). The expansion was designed to permit processing of additional types of combat vehicle engines; the alternative consisted of continuing manual rebuild and testing of the subject engines. Since the proposed expansion involved the procurement of additional computer capability, the analysis time frame was set at 8 years—the estimated life for the ADP equipment.

The analysis of alternatives with different economic lives can be conducted in several ways which depend on the exact nature of the alternatives and the primary purpose of the analysis. Regardless of the approach taken, an assumption must be made on the terminal value of at least one of the alternatives—that is, the remaining value of assets at the end of the analysis period. This generalization is illustrated below.

The example presumes an analysis in which an alternative with a 10-year economic life is being compared to one with a 15-year life. Two approaches could be followed in the analysis. Either a 10-year time frame could be used or a 15-year time frame with the further assumption of two buys of the 10-year life alternative. Under the first approach it would be necessary to assume (or compute) a terminal value for the longer-lived alternative; under the second it would be necessary to provide a similar value for the shorter-lived alternative. An assumption of zero terminal value is not only permissible, but in many cases appropriate.*

[10] US Army Munitions Command, "Automatic Checkout System for Combat Vehicle Engines and Transmissions (DepotMAIDS)," Dec 72.

*The concept of uniform annual cost is particularly useful for comparing costs of alternatives with different economic lives. App A discusses the concept in detail.

Production/funding leadtime considerations contribute their own types of complexity into the determination of analysis time frame. To over simplify, the major source of complexity derives from the fact that payments for goods and services often precede delivery. Thus, costs are incurred for an investment before the investment begins to yield benefits. Under such circumstances the determination of analysis time frame becomes essentially a two-step process. The period from the date of delivery to the end of the analysis period is based primarily on economic life; the period preceding delivery is determined by the assumed leadtime between delivery and initial production date together with any further leadtime between initial production and initial funding.*

Section V of the Munitions Command (MUCOM) Economic Analysis Manual[11] contains an excellent discussion of the impacts of leadtime considerations, particularly those related to the estimation of the disbursement pattern for a given total leadtime. For illustration, the manual introduces a hypothetical construction example involving disbursements over a 3-year period prior to completion of a building project. Salient points are summarized in the following paragraph.

The potential sources for estimating the disbursement pattern vary in form and in degree of association with the particular construction project. They include estimates from Army engineers, contractual documents, and Corps of Engineer guidance. The analyst may be able to establish a 3-year disbursement pattern based on projected percentage completion at the end of each of the first 2 years. On the other hand, the analyst may be limited to allocating the total construction cost equally to the 3 years. It all depends on the sources available to him and the detail included.

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*Funding, as used here, refers to disbursements rather than obligations. Disbursements represent actual payments, whereas obligations represent legal commitments for subsequent payment.

[11]Army Munitions Command, Office of the Comptroller, Cost Analysis Division, Economic Analysis Manual, Mar 72.

Quantity. This section is directed to high-order assumptions that impact on equipment, personnel, and workload quantities. Examples of high-order assumptions include ones involving force structure, tables of organization (TOEs), and logistic policies (e.g., those related to field reserves and depot stocks.) The cited assumptions are particularly crucial to analysis of a weapon/support system such as the Combat Service Support System (CS_3). However, they also affect more limited proposals, as will be shown through reference to DepotMAIDS.

The division-dedicated CS_3 configuration considered in the latest CS_3 economic analysis[12] provides an example where general force structure assumptions with respect to the number of corps and number of active Army divisions basically determined the major equipment requirements—the CS_3 sets. Each corps (four) and each division (13) in the assumed force structure was assigned a CS_3 equipment set consisting of a mobile IBM 360/40 computer and eight remote terminals. Personnel requirements were developed on a more detailed basis, involving construction of a type corps and line item analysis of personnel authorizations in divisional and nondivisional TOEs.

The latest DepotMAIDS economic analysis[10] (see Vol IV) provides an example where an implicit assumption of no change in the post-Vietnam Army force structure (overall size and composition of combat elements) underlies the estimated workloads of combat vehicle engines. After a scheduled one-time influx of engine assets from Vietnam for fiscal year 1974 (FY74), the projected workload for each engine is estimated at a lower constant sustaining level for FY75 through FY81.

Force structure assumptions may have a one-dimensional impact by affecting quantities only. This is essentially the case for both the CS_3 and DepotMAIDS studies. In other analyses, however, the assumptions may have a compound influence, affecting both quantity and unit cost. For such analyses it is imperative to construct a variety of plausible force structures in order to measure the sensitivity of total cost to force structure.

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[12] Office of the Assistant Vice Chief of Staff, Management Information Systems Directorate, "Combat Service Support System Cost Effectiveness Update," 10 Jul 72.

When related, quantity and unit cost are generally inversely related. That is, unit cost declines with increasing quantity. Two separate factors account for the inverse relation. First, increased quantity often necessitates greater utilization of capacity and a concomitant spreading of overhead costs to a greater number of units. Second, increased quantity often permits economies (the learning effect) to be introduced in the production process.

Capacity utilization is a particularly crucial element in determining the production costs of ammunition. The following excerpt from a MUCOM publication[13] (reproduced as App E of RAC-TP-449[14]) summarizes the situation:

> A substantial amount of the production of ammunition and its components is undertaken in (Government-owned, contractor-operated) GOCO facilities. These facilities are often operated at utilization rates far below those found in commercial plants and thus have a higher overhead to direct cost ratio. When production of ammunition is at a high level, as it has been over the last several years (FY69-FY71), the GOCO plants tend to operate nearer optimum capacity and thus produce at lower cost.*

The production costs of military hardware, particularly equipment items that are large, complex, and subject to frequent design changes, vary in a fairly regular manner with the cumulative volume of production. This regularity has been described as "the learning phenomenon" and has been expressed algebraically and graphically as "the learning curve."

The learning curve principle is that each doubling of cumulative production will be accompanied by a constant percentage reduction in cost, the rate depending on such factors as type of item, closeness to predecessor items, and mode of manufacture. Cost under one learning curve formulation represents the cost of a particular unit (e.g., unit 100) and under a second represents the average cumulative cost

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[13] US Army Munitions Command, Cost Analysis Division, "A Cost Estimating Relationship for Small-Arms Cartridge Cases," Report CAD-71-1, Feb 72.

[14] Alfred D. Stament and Carl R. Wilbourn, "Cost Estimating Relationships: A Manual for the Army Materiel Command," RAC-TP-449, Research Analysis Corporation, May 72.

*The lower costs of ammunition cited here, of course, are primarily a result of Vietnam activities rather than force structure influences.

(e.g., the average cost of units 1 to 100). Learning curve essentials are presented in App B; a discussion of wider scope is included in Ref 14, Part II, Chap. 2.

Activity Levels. Operating costs in many analyses will be highly dependent on assumed activity levels or rates. One of the classic examples of such dependence is the aircraft system cost-effectiveness study. A "typical" aircraft system model formulated in one review[15] of cost models includes flying hours as one of the determinants in the following kinds of cost:

a. Initial training and travel costs of airframe mechanics
b. Annual replacement and travel costs of airframe mechanics
c. Annual pay and allowances of airframe mechanics
d. Petroleum, oils, and lubricants (POL) initial stockage cost
e. Annual aircraft replacement cost
f. Annual aircraft POL consumption cost
g. Annual aircraft maintenance parts cost

Monthly wartime flying hours enter into the determination of the first three cost elements and annual peacetime flying hours into the remaining four (see Ref 15, pp 25-27).

The dependence of cost on activity rates is obvious in aircraft system applications and in combat vehicle applications (where miles takes the place of flying hours as a major cost-driving parameter). It is difficult to see how an analysis in such areas can be complete without taking into account ranges of possible activity levels to ascertain the effect on costs. This line of reasoning is pursued at length in Section 4, and methods are discussed for examining the sensitivity of costs to assumed activity rates and other parameters.

Analyses frequently are based on the assumption that current (or, perhaps, Vietnam-free) activity levels will continue into the future.

[15] Alfred D. Stament, "An Individual System/Organization Cost Model," RAC-TP-183: Vol IV, "Review of Selected Applications," Research Analysis Corporation, Dec 67.

The CS_3 analyses implicitly assume continuation of the current level of activity. The latest DepotMAIDS study[10] addresses activity levels at LEAD as follows:

> It is assumed that the level of activity will increase due to a large influx of assets from Vietnam in FY74 and then sharply decrease to a sustaining level of peacetime Army in FY75 and out years, and this level is reflected in the published [FY75] workload projection data.

Implicitly, the postulated LEAD activity levels for FY75 and beyond assume constant annual peacetime operating rates for combat vehicles and, as previously indicated, a stable force structure.

<u>Degree of Support</u>. The out-of-pocket costs required to implement a proposed investment are reduced to the extent that the investment can make use of inherited assets, i.e., existing facilities, equipment, and personnel. They also are reduced to the extent that required activities can be performed by existing organizations or installations. This might occur in the area of administration, for example, where an activity is scheduled to be satellited on a host installation.

Guidance[7] concerning inheritance of physical assets and imputation of any costs therefor is explicit, as is shown in the following excerpt:

> The investment for a given project may consist of assets to be acquired <u>plus</u> existing assets, i.e., assets already on hand. However, the value of such existing assets will be included in the investment costs only when the existing asset is currently in use (or has an alternative, planned use) on some other project or is intended for sale. When such alternative use of the existing asset result in a cash outlay for some other project which would otherwise not be incurred, or will deprive the Government of the cash planned to be realized by sale, the value will be included in the analysis.

Guidance[7] regarding personnel inheritance and associated cost consequences is less straightforward and comprehensive, being limited to the statement that all training and retraining costs that occur which would not have accrued without the investment should be included as a cost of the investment.

Degree of support assumptions of a different kind from those described previously are used frequently to set bounds for an analysis. The need for such assumptions arises from the fact that the direct

operating activities of a proposed investment are facilitated by support activities, that these support activities, in turn, receive support from other activities, and so on ad infinitum. Where the support activities can be reasonably assumed to be common to all alternatives in an analysis, the support can usually be omitted from the cost and benefit determination. Support peculiar to alternatives must be considered in the analysis.

Facts vs Assumptions

In preparing an economic analysis it is important to distinguish assumptions from facts and to label each properly. The validity of an analysis is in question when assumptions are confused with facts or assumptions are used to ease the preparation burden when, with research, factual data could be obtained and presented.

The possibility of replacing an assumption by facts gained through research is illustrated in the following excerpt from the Department of Defense Economic Analysis Handbook[1]:

> If [for example] we are considering landfill as an alternative to solving a disposal problem stemming from increased waste, we might include in the study, the assumption that sufficient land for this operation is available within a 20 mile radius of the installation. However, in this particular instance, there may have been no obstacle preventing us from the research necessary to present this element of data as a fact rather than as an assumption.

Making Assumptions Explicit

Implied assumptions as well as explicit ones impact upon a study. An implied decision is often introduced when several different courses of action are open and a decision is made to proceed in one direction. Such a decision may be erroneously accepted as a known quantity when it is really an assumption.

The analyst should list assumptions as they are made and review them frequently during the course of the analysis. One of the payoffs of frequent reviews is the disclosure to the analyst of any implied assumptions that have been employed. When identified, such assumptions should be made explicit, questioned as to acceptability, and, where acceptable, supported. The final economic analysis documentation

should explicitly disclose all major assumptions so that the decision maker and reviewers will be able to ascertain the basic ground rules on which the study results are based.

Sources and Justifications of Assumptions. Assumptions must be based on sound rationale and justified as part of the analysis process. For example, if an assumption is made that the economic life of an alternative is 15 years, this time frame must be supported. The justification might be along the following lines: "Current R&D efforts will advance technology to the point where the process can be eliminated at the end of 15 years." To take another example, an assumption that the administrative load of a proposed satellite activity could be handled at "no cost" by the host installation might be justified by showing the ratio of proposed activity personnel to total existing installation personnel.

Justification in many cases may mean no more than a reference to the inclusion of the assumption in the tasking order or to compliance with a proper guidance document. For example, an economic life assumption of X years for an elective component in a radar system might be justified by citing the manufacturer's standard of estimated life expectance. The availability of the standard does not alter the fact that an assumption is made concerning economic life.

Previous studies, approved recurring reports, and cost factor publications[16,17] facilitate the preparation of an economic analysis, permitting the analyst to focus major attention on the construction of alternatives and important areas of uncertainty. The primary concern in using these sources is to ensure that the basic data or ready-made factors are appropriate to the problem at hand. Among other things this requires a close examination of the assumptions used in the sources. Those assumptions that contribute materially to the results of the economic analysis should, of course, be prominently displayed in the final documentation.

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[16] Dept of Army, Comptroller of the Army, "Army Force Planning Cost Handbook (U)," Oct 71.

[17] Doris C. Berger, John O'Flaherty, and Joseph String, Jr., "Selected Uniform Cost Factors: A Manual for the Army Materiel Command," RAC-TP-451, Research Analysis Corporation, Jun 72.

Roles and Limitations of Assumptions. Assumptions are properly used to narrow the scope of a study. They should be examined, however, to determine whether they unduly restrict the study by eliminating possible significant alternatives or by narrowing the scope of consideration to the point that conclusions drawn from the study are in error. Assumptions should be limited to areas in which it is either not feasible or not possible to obtain facts.

Assumptions designed to narrow the scope of an analysis are maintained throughout the analysis. Other assumptions, however, are made with the deliberate intention of being changed during the analysis. The use of variable assumptions has a twofold purpose. From an operational viewpoint their use permits the analyst to focus on a set of manageable subproblems, one at a time. From a study results viewpoint, their use is essential to any investigation of the dependence of results on underlying assumptions. Procedures for investigating such dependence are discussed in detail in Section 4.

ALTERNATIVES

There is normally more than one way to achieve a given mission or activity. The various means that compete with one another are referred to as alternatives. Existing systems and policies, the initial problem statement, and the experience of the analyst provide a starting point for the development of alternatives. As the analysis proceeds, the alternatives will become further defined, or perhaps discarded in favor of new alternatives.

Where appropriate, the choice of maintaining the current system (the status quo) should be considered. It may be the best way after all, and even though it may only minimally accomplish the mission, it is important to show its status as an alternative. It will be beneficial later if another alternative is selected to show the comparison between the old capability and the proposed alternatives. The current system also may form a part of another alternative and should be considered there as well.

The decision maker can consider only those alternatives addressed in the analysis. His decision can be no better than the alternatives presented for choice. The analyst's task, therefore, is to construct a meaningful range of feasible alternatives for the decision maker's consideration. Feasibility is determined by whether an alternative satisfies all study objectives, assumptions, and constraints. Imagination and careful attention to objectives go a long way towards determining the proper range of alternatives.

Base Alternative

An economic analysis always addresses at least two alternatives, one of which is usually the existing system or an upgraded version. The alternative that most closely approximates the existing system should be formulated as the base case or status quo. The base alternative, its benefits, and its costs will then serve as common reference points in the analysis. The interpretation of benefits and costs of all other alternatives, perhaps even their derivation, will depend on the particular base case selected for study. It is crucial, therefore, that the analyst constructs a proper base.

Specifying the Base. The term "specification" refers to the process of determining the facilities, equipment, and manning requirements for an alternative. Ideally, specification should be in such detail that important differences between facilities, between items of equipment, and between personnel are isolated, while unimportant differences are ignored. In practice it is often found necessary to specify at a more aggregative level than is desired. Frequently, the data on which cost factors and cost estimating relationships (CERs) are to be based set a practical limit to the level of specification.

Specifying the status quo is intuitively simple. However, proper specification of the base frequently will take considerable time and involves subjective judgments on the part of the analyst. In some analyses the specification of the base may prove as difficult as that of a proposed alternative.

Feasibility of the Base. The base, like other alternatives, must be examined for feasibility. If the formulated base is not capable of

meeting the objectives within the study assumptions and constraints, the analyst should address the changes necessary to meet the objectives. The base alternative must be one that the decision maker can logically choose.

It is realized that in upgrading the base or in altering assumptions and constraints the analyst may be moving close to the decision maker's prerogatives. Where such actions appear in conflict with the tasking order, the analyst should attempt to resolve the issues with the decision maker. That failing, full and carefully presented rationale for following the particular course of action should be included in the documentation.

Proposed Alternatives

The proposed alternatives in an economic analysis derive from two main sources. Some will be included in the tasking order. Often such alternatives have been put forth by proponents with the expectation (or hope) that they will be found economically superior to the status quo. The other source of alternatives resides in the skill and experience of the analyst.

Specification of Alternatives. The importance of defining alternatives cannot be overemphasized. The decision to select an alternative can be no better than the alternatives presented to the decision maker. Even though the proposed alternatives in the tasking order may be demonstrably superior to the current system, it does not follow that they are superior to other feasible alternatives that the analyst might construct. As one source[12] has succinctly stated, "The substantive quality of the analysis depends on postulating feasible and imaginative alternatives."

It is the analyst's job to propose new ideas and new alternatives. The traditional, conventional, or seemingly most plausible way of performing a task is not the only way. As more is learned about the area of concern, more alternatives should suggest themselves. Throughout the study the analyst should remain flexible with regard to acceptance of new alternatives and discarding of old ones.

In certain studies it may be appropriate to consider the capabilities of other DOD components or Federal agencies to meet Army requirements. A study of meeting data processing needs, for example, might properly

consider an option establishing a regional computer system to service the data processing needs for an Army installation, offices of the Federal Aviation Administration, and offices of the Interior Department.

For other studies, it may be appropriate to consider various mixtures of Army systems as alternatives. For example, in comparing transportation systems, several alternatives for surface transportation might be formed from different combinations of truck, rail, and water modes. Similarly, alternative proposals for increasing the productivity of a supply system might include different combinations of automated and manual subsystems.

Identifying Problem Areas. Alternative specification is not merely a tallying of hardware and personnel requirements. It is also a great opportunity for the analyst to inquire into the major uncertainties surrounding an alternative. Descriptions of proposed systems and their capabilities, whether prepared by the analyst himself or produced by proponents, invariably stress the positive. During the specification of an alternative the analyst should pose a series of "what if" questions. These can provide insights into how adaptable the alternative might be to a variety of unfavorable circumstances. As discussed in Section 4, crucial "what if" questions should be absorbed into a formal uncertainty analysis.

3 COSTS

INTRODUCTION

Economic analysis involves the assessment of both costs and benefits. This section discusses costs, and Section 4, which follows, discusses benefits. In general, cost analysis is concerned with resource inputs and benefit analysis is concerned with resulting outputs. Using this delination, the cost and benefit components of economic analysis may be characterized as follows:

Cost analysis is a systematic determination of the real resource requirements (personnel, equipment, and facilities) of all candidate alternatives and the translation of such requirements into estimated dollar costs.

Benefit analysis is a systematic determination of the outputs of all candidate alternatives. Where possible, the outputs are quantified in terms of dollars, performance indicators, or physical measures. Narrative descriptions are provided for nonquantifiable benefits.

The subsections which are discussed in this section are cost concepts and definitions, methods of estimation, system development considerations, data considerations, and cost model considerations. Section 4 presents a parallel treatment of benefits. Problem areas in both cost and benefit are identified even where ready answers are lacking or incomplete.

CONCEPTS AND DEFINITIONS

While there are several concepts of cost, only the primary cost concepts need to be mastered in order to provide a background for economic analysis applications. The primary concepts are discussed here. Definitions of additional terms are provided in App B.

Opportunity Cost

Resources used in one activity cannot be used at the same time in another. The value foregone from using the resource in an alternative use is referred to as opportunity cost. Thus, the opportunity cost of the steel used for making tanks is measured by its unavailability for making automobiles. Similarly, the opportunity cost of the synthetic fibers contained in a soldier's uniform is measured by its unavailability for a party dress.

Price. Under the idealistic conditions of perfect competition in factor and product markets, the price of a commodity may be used to measure its opportunity cost.[18] For example, under conditions of perfect competition the price of a ton of steel would exactly measure its common value in the production of tanks and automobiles.

Price Levels. Prices for goods and services vary over time and geographical area. A price index is a summary number that reflects a price level change from one period or place to another. The use of a common base provides a means for making dollar totals of different years or places comparable. Generally speaking, the analyst will be more concerned with time-based price indexes than with geographical ones. The latter are of importance in certain areas such as construction, however, and are the subject of a special AR.[19]

The sample indexes for ordnance and related accessories published[20] by the Weapons Command (WECOM) will be used in the succeeding paragraph to illustrate the general relation between price level and price index:

Year	Labor Index	Material Index
1960	100.0	100.0
1961	104.1	99.0
1962	106.5	98.9

[18] Paul A. Samuelson, Economics, 8th edition, McGraw-Hill Book Company, New York, 1970.

[19] Dept of Army, "Empirical Cost Estimates for Military Construction and Cost Adjustment Factors," AR 415-17, 26 June 1972.

[20] US Army Weapons Command, Cost Analysis Office (AMSWE-CPD), "Inflation and Military Price Indices," Publication No. 70-21, November 1970.

The price index for the base period is defined as 100 and all other indices are interpreted with respect to the base. In this example the base year for the ordnance indexes is 1960, as shown by the 1960 index value of 100.0 for both labor and material. The labor index of 104.1 for 1961 indicates that the price level—or average prices paid for a common amount of labor in ordnance production—would be 4.1 percent higher in 1961 than 1960. Similarly, the labor index of 106.5 for 1962 indicates that a common amount of labor would cost 6.5 percent more in 1962 than 1960. In this example the material index is smaller in each successive year. This implies that the average price for materials is declining, e.g., the price of materials in 1962 is 1.2 percent less than in 1960.

The terms "constant dollars" and "current dollars" are frequently encountered in economic analyses. Constant dollars refer to real value over time, or the measurement of value over time with a correction made for price changes. On the other hand, current dollars refer to values which are uncorrected for price changes. For example, if it is assumed that the average hourly wage rate was \$3.48 (current dollars) in 1960 and the average hourly wage rate was \$3.85 (current dollars) in 1962, then the real wage rate or the wage rate in constant dollars (base 1960) for 1962 is \$3.62, e.g.,

$$(3.85)\frac{100}{106.5} = \$3.615$$

Constant dollars are measured in terms of real purchasing power with respect to a specified base year. The formula for converting current dollars into constant dollars is

$$\text{Constant dollars (period t)} = \text{current dollars} \times \frac{\text{price index (base)}}{\text{price index (t)}}$$

<u>Imputed Costs</u>. Payments are made for acquisition of all new resources. An activity, however, may make use of existing assets as well as newly acquired ones. The use of existing assets raises two questions. Should an activity be charged with an imputed cost for the utilization of such assets? If so, what determines the cost magnitude?

AR 37-13[7] guidance on these questions reduces to an affirmation of the opportunity cost concept. The AR states that an imputed cost should be added to the investment costs of an activity wherever the asset has

an alternative use. The value of the asset in the alternative use, including any expected return from asset disposal, establishes the imputed cost. Although not specifically addressed, the imputed cost should be set at the highest value when there is more than one alternative use for the asset.

Residual Value. A project may have several assets that are expected to physically outlive the project's economic usefulness. The value of these assets, if any, at the end of project life is independent of what the assets originally cost. The residual value is the net value of the asset in the most favorable alternative use after allowance for any necessary costs of dismantling and removal.

AR 37-13[7] directs that any estimated residual value of assets should be treated as an offset to the cost of the project for which they are originally intended. The residual value must be properly discounted to a present value amount and supported with justification.

Present Value

In every investment, explicit recognition should be given to the fact that a dollar today is worth more than a dollar to be received sometime in the future. Present value calculations provide a means for comparing dollar amounts received or expended in different years. Fundamental to the concept of present value is the fact that money has time value. Like all resources, money is productive and because there is a strong preference for having a dollar today as compared with having a dollar at some future time, payment of interest is required for the use of money. The interest rate is the necessary tool for converting costs and benefits occurring at different points in time into an equivalent cost and benefit occurring at the present time.

The technique or calculations required to determine the present value of a cash flow is called discounting. The term comes from the fact that an amount in the future is discounted back to some lesser present value (remember a dollar today is worth more than a dollar sometime in the future). The mechanics of discounting are described in the Discounting section of App A.

The interest rate used in the calculation of present value is normally determined in one of two ways. The first is simply the cost of capital method. This is the rate which a borrower is charged in order to use a lender's money. The second method is called the opportunity cost of capital. This situation is used where the capital to finance a project is held by an investor and does not have to be borrowed. In this case, the interest rate is determined as that rate which could be received if the same money were lent or invested rather than used to finance a particular project.

Economic analysis guidance[1] specifies the use of a 10 percent interest rate in present value calculations for all but a limited number of Army investments. This rate is intended to represent the opportunity cost of capital in the private sector of the US economy.[2] That is, the returns that are foregone by investing in Federal projects rather than private projects. The rate is not intended to incorporate considerations of uncertainty or of inflation, but just the time value of money to the Federal government.

The general formula for calculating the present value (PV) of A dollars t years from now at a constant interest rate i compounded annually is as follows:

$$PV = \frac{A}{(1+i)^t}$$

For example, the present value of $121 to be received in two years is $100 if an annual rate of 10 percent is used.

$$100 = \frac{121}{(1+.1)^2}$$

The underlying rationale is that if $100 were invested today at an annual rate of 10 percent for a year and the principal and interest subsequently invested for another year, then the total return at the end of two years would be $121.

Where the alternatives being compared have differing economic lives, the direct comparison of present value costs will generally identify the longer-lived alternative as the more expensive. Restricting an analysis to comparison of present value costs would clearly involve placing a penalty on the longer-lived alternative. A measure of the average cost per productive year is needed to compare the alternatives. This average cost is referred to as the uniform annual cost.

Uniform Annual Cost

The concept "uniform annual cost" assumes that the discounted present value of projected costs can be uniformly distributed over the useful life of the investment. Uniform annual cost should be used whenever alternatives have different project lives. Uniform annual cost is obtained by dividing the total present value cost by the sum of the discount factors for the years in which the alternative yields benefits. The alternative with the smallest uniform annual cost is assumed to be the least costly alternative. Comparison of the present value costs of alternatives with different project lives is never appropriate; the only valid comparisons are those on the uniform annual costs. Appendix A discusses the uniform annual costing method and illustrates how it is derived from present value costs.

Future Costs vs Past Costs

Economic analysis is concerned with the future costs of alternatives. Future cost estimates present the decision maker with the expected cost consequences of making various decisions. Past costs are beyond the reach of any decision that might be made.

Incremental Marginal Costs. The incremental (marginal) costs of an alternative consist of all costs which are directly attributable to the implementation of the alternative. Costs which would have occurred regardless of whether or not the alternative was implemented should not be included. From the standpoint of planning, all incremental costs are future costs.

Sunk Costs. Sunk costs are the costs that have been expended prior to the beginning of the study time frame. They should not be included in a cost comparison, but should be shown separately as supplementary information. For example, if two alternative communications systems are being considered for development and $2 million of R&D funds have been spent on one of the alternatives, while no funds have been spent on the other, then the $2 million expenditure is sunk and should not be included as cost when comparing the two alternatives.

Cost Estimating. Past costs are of vital interest to the analyst. Costs experienced in the past provide the most reliable means for generating expected future costs. Generally the analyst will have to expand his investigation beyond the alternatives being considered as candidates in the economic analysis in order to develop meaningful cost estimates. Collection of cost data on the status quo, though essential, may not be sufficient.

Life Cycle Costs

The life cycle costs of an alternative include all associated costs from inception through implementation and operation. Life cycle costs are categorized on the basis of research and development (R&D), investment, and operating costs. Definitions of these basic cost categories follow:

Research and Development. Includes all costs necessary to design a project or system and to perform development testing. R&D costs encompass efforts devoted to components and to their integration into an overall project or system.

Investment. Includes all costs required to introduce a fully designed project or system into operation. This category includes all nonrecurring (i.e., one-time) costs incurred in the acquisition of equipment, facilities, supplies, and services. This restricted definition of investment should not be confused with a broader usage employed in Army guidance. Investment in the broader sense means any future utilization of resources.

Operating Costs. Includes all recurring costs associated with the compensation and training of personnel and the operation and maintenance of plant and equipment.

Costs - Current Dollars vs Constant Dollars

Past costs reflect the prevailing price levels of the years in which the costs were experienced. Price indexes are used to remove the disturbing influences of general price movements. Original or unadjusted past costs are referred to as current or nominal costs, whereas those that have been adjusted through application of price indexes are referred to as constant or real costs. Constant costs are always based on price conditions that existed during some selected time period, generally a selected year.

The propriety of using empirically derived indexes to adjust historical cost data is universally recognized, although differences of opinion exist on how to construct a proper index and on the extent to which indexes developed from the private sector are appropriate for DOD expenditures. The use of projected indexes to convert constant dollar estimates to current dollar estimates for future years, on the other hand, has led to considerable controversy and confusion. Here future price movements are forecast rather than past movements measured.

The economic analysis guidance[5,7] is firm and clear on the use and limitations of projected price indexes (inflation rates) for future years. Evaluation of alternatives is required, using the general purchasing power of the dollar existing at the time the analysis is prepared. It is mandatory that the principle evaluations of the alternatives be based on constant (uninflated) dollars. However, supplementary analysis using current (inflated) dollars is encouraged where "inflation is considered important to the conclusion of the study."[5]

METHODS OF ESTIMATION

A variety of methods is available for estimating costs. Some of the important methods are discussed in this subsection and are as follows: cost factors, cost estimating relationships (CERs), analogy costing, industrial engineering costing, and expert opinion costing.

Cost Factors

A cost factor is "a single multiplier such as a cost per unit of resource, or a ratio relating the cost of a portion of a system to the cost of another controlling portion of the system."[21] The majority of cost estimates are made by applying cost factors.

Cost factors include averages derived by the analyst from empirical records, planning factors published in special handbooks,[16,17] and standard prices listed by the Army[22] or contractors. Examples of operating rates and POL cost factors from Ref 17 follow:

M113A1 armored personnel carrier average miles per year = 1572
M113A1 gallons per mile = .62
Army stock fund price per gallon for diesel fuel - $0.12
Ground equipment nonfuel POL costs = .08 x ground equipment fuel costs

The use of the above operating data and cost factors in estimating the annual POL costs for an M113A1 follows:

Annual M113A1 POL costs = 1572 x .62 x $0.12 x (1.08) = $126

Cost Estimating Relationships (CERs)

A cost estimating relationship is an equation that relates costs of an item or an activity to one or more physical or performance characteristics. The CER development process consists of three distinct phases. These are 1) identifying a population of related items or activities; 2) collecting historical data [e.g., cost, performance, technical characteristics, and program data on each member of the population]; and 3) deriving a generalized relationship through statistical techniques. CERs for the most part are developed through application of standard regression analysis (see App C).

One of the most challenging aspects of CER development is the identification of logical cost-driving explanatory variables and the formulation of the underlying mathematical relationship between cost and the selected explanatory variables. Stament and Wilbourn discuss these subjects in detail[14] (see pp II-1-35 to II-1-36).

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[21] Bruce N. Baker, "Improving Cost Estimating and Analysis in DOD and NASA," Doctoral Dissertation George Washington University, Jan 72.

[22] Dept of Army, "Army Adopted and Other Items of Materiel Selected for Authorization," SB 700-20, 30 Nov 71.

All physical and performance characteristics regarded as potential cost drivers for systems in the CER sample and for future systems should be evaluated as possible candidate independent variables. If the cost analyst is thoroughly familiar with the class of systems under investigation, he may be able to select the most appropriate characteristics. In general, however, he should rely on an "expert" in the field, such as a project manager or engineer, to assist him in this selection. Often people with a technical orientation can suggest related variables for which data might be collected. Thus, for example, velocity might be considered as a candidate variable for missile production costs. In addition to velocity, it might prove useful to have related measures such as engine thrust, total impulse, and the ratio of total impulse to weight.

Depending on the particular application, there may be independent variables other than physical and performance characteristics that might be significant. For investment CERs, variables such as total number of production units, production rate, and number of prototype units produced are possible candidates. For operating CERs, vehicle age and cumulative operating hours or miles are possibilities. Also, the geographic area of operation could be an important variable because it might lead to a stratification of the sample.

An example of a digital computer CER developed jointly by personnel from the Electronics Command (ECOM) and GRC follows:

$$C = 105 + 2.90 A + .157 S + 709 \left(\frac{1}{T}\right)$$

where C = cost in thousands of dollars,
A = number of bits accessed per memory cycle time (bits per microsecond),
S = core storage size (thousands of bits),
T = fixed-point add time (microseconds).

The CER was developed on the basis of 11 third-generation computers. The CER accounted for over 95 percent of the total variation of cost for the sample computers. Further details on this CER and a related one based on the same sample are provided in Annex A2 of Ref 14.

Analogy Costing

Analogy costing has been used in Army applications more than costing through CERs. The simplicity of the approach relative to that of CERs is

undoubtedly one of the reasons. Another is that analogy costing often can be applied where development of CERs is impossible or not warranted from the viewpoint of time and cost. The analogy approach can be used to estimate the cost of any equipment item provided that technical specifications can be secured for a single comparable predecessor. Cost and technical data on several predecessor items would have to be collected in order to develop a reliable CER.

The analogy approach typically assumes that cost is proportional to the magnitude of some technical characteristic. For example, a doubling of weight is assumed to double cost. In one application[23] POL cost per mile was assumed to be proportional to the number of cylinders in the vehicle engine. The number of cylinders in the Sheridan engine and in the proposed engine for the austere combat vehicle (MICV) were combined with POL experience data for the Sheridan to estimate POL cost for the MICV as follows:

$$\frac{\text{\# engines MICV}}{\text{\# engines Sheridan}} \times \text{POL cost Sheridan} = \text{estimated POL cost MICV}$$

$$\frac{8}{6} \times \$.0670 = \$.0893.$$

Industrial Engineering Costing

The industrial engineering approach to cost estimating is used primarily to estimate hardware production costs and involves the consolidation of separately developed cost estimates formed from detailed analyses of work processes, material, and item dimensions. The approach is feasible only when technical data packages and drawings are in hand; it is time-consuming and exacting even when such equipment descriptions are available.

In the industrial engineering approach the total production process is divided into work segments. The direct costs of each work segment are then calculated by applying current cost factors to the estimated labor and material requirements. Typically, overhead and assembly costs are based on the work segment resource requirements and/or estimated costs. Such diverse costs as tool maintenance, quality control, and manufacturing research in certain applications may ultimately relate back to the basic direct labor estimates.

[23] Lt W. A. Holman, "Annual Operating Costs of the Austere Mechanized Infantry Combat Vehicle (MICV)," WS-103-71 US Army Field Operating Cost Agency, Nov 70.

Procurement personnel and members of "should-cost" teams may find themselves frequently involved in industrial engineering cost estimating. The approach, however, would appear to have limited application in economic analysis. Generally, the analyst would have neither the necessary information nor time to develop true engineering estimates. Make or buy studies (for example, production of ammunition in arsenals or purchase from commercial producers) may be one area where industrial engineering estimates would be appropriate.

Expert Opinion Costing

Expert opinion costing may be viewed as the primitive application of formal costing methods by an experienced individual. For example, the procurement officer on a military installation gains an intuitive sense of the cost of supplying the installation with certain line items over time. While he may not go through the formal steps of analyzing cost and requirements, his experience may be adequate to provide reliable cost estimates for similar operations at another installation.

It is arguable whether expert opinion or judgmental costing should be considered as a separate method of cost estimating. However, it is appropriate to mention it, and it can be distinguished from parametric cost estimating in that the latter is accompanied with supporting information regarding cost, performance, physical dimensions, or other specifications.

SYSTEM DEVELOPMENT CONSIDERATIONS

The feasibility and propriety of using the different types of cost estimating methods are determined by the availability and quality of input data. These, in turn, depend primarily on the stage of development of the subject system or systems. Figure 2 depicts some useful generalizations that can be made concerning stage of development, input data, and broad type of cost estimate.

Figure 2 suggests a tendency for the quantity of hard input data (supportable numbers vs guesses) to grow as the system passes from the conceptual stage to the operational stage and a concomitant tendency for data uncertainty to vary in the opposite direction. As the system moves toward the operational stage, less reliance can be placed on opinion and

parametric estimates and more on industrial engineering estimates or even actual system operating data. The areas in the rectangles on the right-hand side of the figure give some idea of the use of the different types of "cost estimates" by stage of system development.

DATA CONSIDERATIONS

Cost and technical data for a study are generated from three general sources. These include existing studies and management documents, operating reports from existing information systems, and field or test results.

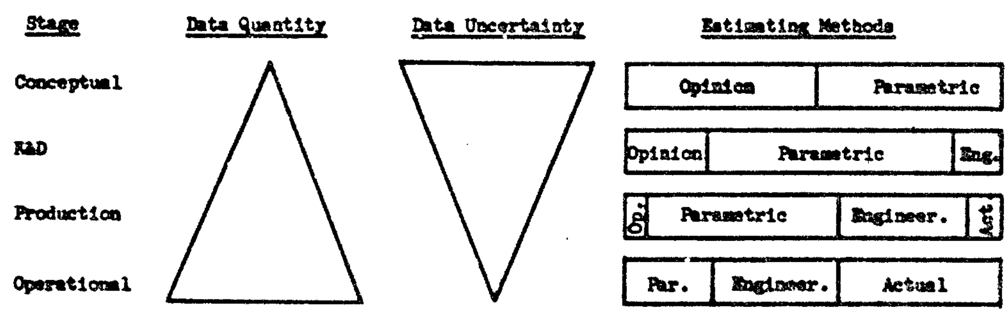

Fig. 2—Relation of Development Stage to Data Inputs and Estimating Methods

Cost Sources

Studies and Documents. The primary concern in using existing studies or management documents is to ensure that the basic data or ready-made factors are appropriate to the current study. This cannot be done adequately on the basis of similarities in nomenclature. Appropriateness can only be determined by thorough examination of descriptions and calculating methods provided in the source publications. Obviously if the analyst is unsatisfied with the documentation or method of calculation for a given information element, the source should not be used for that element.

A second concern with published sources is whether or not the data are current. Cost data have a tendency to become outdated rather quickly. Thus, even though a source properly identifies the composition and method of calculating a cost factor, the factor might require updating to be

useful. Where a question of updating arises, it is often best to contact the originating agency to ascertain the possible need for and availability of updated information.

In addition to special cost handbooks (e.g., Refs 16 and 17) and existing studies, the following types of documents contain cost data and factors:

- Contract files
- Cost Information Reports
- Procurement Information Reports
- Army catalogs
- Army Materiel Plan
- Commercial price lists

Each of these sources is discussed in Ref 14 (Part II, Chap. 2) and exemplified to the extent possible by the field work underlying the study, by reproduction of report formats, and by inclusion of extracts from the COA Methodology Handbook.[8] The COA publication also contains discussions of additional sources, particularly those relevant to the early planning stages (see Ref 8, Chap. 3).

Operating Reports. Most information systems are established to serve the needs of managers of operational activities such as maintenance and supply, or for financial control, or for a staff activity such as personnel. The reports from these systems do not necessarily lend themselves to the needs of the economic analyst. Experienced analysts should find little trouble agreeing with the following observations from Jestice[24]

> It appears that in every study we've done, whether it is in the education, military or mining fields, the data that are available rarely address themselves to the fundamental questions that are required in decision-making. The data are gathered because someone developed a lot of enthusiasm about collecting this type of data.

Despite these limitations, standard operating reports are useful during the performance of an economic analysis. The reports required

[24] Aaron Jestice, "The PATTERN Method and National Defense Requirements," Rose Glubin, ed., Office of the Assistant Secretary of Defense (Comptroller), Benefit/Output in Economic Analysis in the Department of Defense, Jan 73, pp 55-83.

under AR 18-3[25] provide a case in point in the ADP area. These reports were used in the CS_3 economic analysis studies and are referenced in Vol IV. Maintenance reports such as those published by the Logistic Data Center and Depot Maintenance Control Center are additional examples. These are discussed in Ref 14 (pp II-2-26 to II-2-28).

AR 335-11[26] provides a list of recurring reports by initiating agency. Each report title is accompanied by information on the frequency of preparation, implementing directive (for example, AR, DODI, letter), and preparing agencies. The analyst should familiarize himself with AR 335-11 and the types of reports submitted in his functional area. This means examining directives and sample reports. When a study assignment arrives, the analyst who has done his homework in these areas will be in a better position to judge how much assistance can be expected from recurring reports.

Field or Test Data. In many studies it is necessary to secure field or test data to properly compare costs (and benefits) of system alternatives. Planning, collection, and analysis of such data is typically time-consuming and expensive. Succeeding paragraphs address several considerations that should be kept in mind when planning for the collection of "original" data.

The analyst should first convince himself that the data elements under consideration are important enough to the economic analysis to warrant the special data collection effort. The purpose of the analysis, it must be remembered, is to aid in the selection of the best alternative rather than to strive for cost accuracy per se. Special collection efforts thus should be limited to those activities and costs where considerable differences among alternatives are expected.

When a special data collection effort has been judged worthwhile and capable of being accomplished in sufficient time for application to the problem at hand, the analyst must then:

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[25] Dept of Army, "Automatic Data Processing Management Information System," AR 18-3, 10 Nov 71.

[26] Dept of Army, "List of Approved Recurring Reports," AR 335-11, 7 Jun 1972.

- Define exactly what each element includes and excludes.
- Outline how each element is expected to be collected.
- Determine the requisite sample sizes for statistical significance.
- Determine where the data should be collected.

Sampling and experimental design concepts are discussed in Section 6. The analyst should familiarize himself with these considerations in order to achieve optimum return of information. For detailed assistance the analyst should consult the RAND survey[27] of sampling techniques which is oriented towards military applications.

Technical Characteristics Sources

Many economic analyses can be performed with little or no need for physical and performance data. Such data, for example, were not an integral part of either the CS_3 or DepotMAIDS analyses (see Vol IV). Each of these efforts, however, addressed close-in, well-defined alternatives. Actual operating cost data was available for many elements of cost. Analyses directed to systems in earlier stages of development would have a greater need for parametric estimating and a parallel need for physical and performance data.

Project managers and engineers within R&D Directorates are excellent sources of system technical data. For parametric costing (particularly employment of CERs) it must be remembered that technical specifications are required not only for the systems of immediate interest but also for as many related past systems as feasible.

Special technical data sources vary by type of system. The PMP is a valuable source for a project-managed system. The most common published sources of physical and performance characteristics follow:

- Developmental systems
  - Qualitative materiel requirements
  - Small development requirements

[27] G. C. Sumner, "Sampling Method: Suggestions for Military Cost Analysts," RM-5779-PR, The RAND Corporation, Oct 68.

- Current and past systems
  - Development documents (including above two sources)
  - Prior studies
  - Contract files
  - Commercial publications
  - Army publications
    - US Army fact sheets
    - Technical manuals
    - Special texts

Each source in the preceding list is discussed in Ref 14 (Part II, Chap. 2). The difficulty of securing good technical data should not be underestimated, and the analyst should be both critical and circumspect in his treatment of technical data. These strictures apply to current and past systems as well as to systems under development.

Data Analysis and Adjustment

Locating good, reliable data in sufficient quantity is a major problem. An analyst may devote more effort and time to the collection, adjustment, and reduction of information than to any other aspect of the economic analysis process. Since the end result can be no more reliable than the input data, care should be used in collecting and manipulating the data. The existence of a thorough, carefully prepared data collection plan will help prevent committing the error of gathering the wrong data.

The analyst will frequently encounter the problem of small-sized samples and in many cases little can be done. The statistical uncertainty associated with small-sized samples will have to be recognized and accepted. In other cases the analyst may find that there is an opportunity to increase the data sample through use of estimates, further data collection efforts, or results of experiments.

Cost. The subsequent paragraphs of this subsection discuss some of the more important and frequent types of data analyses and adjustments to cost data. These include comparability analysis of cost data, conversion of cost data to constant dollars, and adjustments for production quantity. The presentation has been abstracted from discussions included in the RAC CER Manual[14] (Part II, Chap. 2). Appendix B of the present volume contains detailed descriptions of price indexes and learning curves, the latter being used to allow for variations in production quantity.

Comparability Analysis. Comparability analysis should be conducted concurrently with the data collection effort and it involves the detailed examination of the composition of each cost data point. The data collected must meet all the criteria specified by the population definition. That is, all pertinent costs must be included and all others excluded. Where questions of composition exist, assistance should be sought by contacting those regarded as knowledgeable in the particular area, especially those whose responsibilities might have brought them into contact with the basic data.

The problem of data comparability is severe when multiple sources are utilized. However, care also must be exercised when there is a single data source. For example, if contract files are the only source, the analyst must make a thorough analysis of all line items. It is usually difficult, without the assistance of the contracting officer, to interpret some of the line item descriptions or to determine whether some other items should be included. In addition, the analyst must ensure that all relevant costs be collected that are not listed in the contract, such as Government furnished equipment (GFE) or components procured from a supplier other than the prime manufacturer.

Conversion to Constant Dollars. Costs incurred in different years are not directly comparable because of changes in the general price level. Therefore, when the cost data collected represent expenditures in different years, it is necessary to convert all costs to a common base. Normally all costs are converted to current FY dollars.

Table 1 provides an example of price indices for airframes. The table is included for illustration purposes only. The table should not be considered as containing approved DOD/DA price indices.

As indicated in Table 1, FY68 is the base year. In order to convert cost incurred in other years to FY68 dollars such costs should be divided by (or multiplied by the reciprocal of) the index opposite the year in which the cost was incurred. For example, a cost incurred in FY71 would be divided by 1.1387 to arrive at the equivalent FY68 cost.

Table 1

AIRFRAME INDICES
(Base, FY68)

FY	Index
1967	0.9457
1968	1.0000
1969	1.0483
1970	1.0951
1971	1.1387
1972	1.1783

If another base year were desired, a new table could be generated by dividing all indices in the column by the index of the base year. Thus, if FY70 were the desired base, the above table could be converted to that base year by dividing all indices by 1.0951.

Cost-Quantity Adjustments. When developing a parametric estimate for the acquisition cost of a system, the basic cost data collected for the sample systems, in general, will not be comparable because they represent different cumulative production quantities. For example, the cost of the 100th unit of one aircraft cannot be compared directly to the cost of the 500th unit of another aircraft because the latter has had the benefit of more "learning." To make the costs of all sample systems comparable, it is necessary to derive a learning curve for each or to apply some accepted industry standard. By following either approach the analyst will be able to estimate sample system costs at like quantities. Figure 3 depicts the translation of an "actual" cost at unit 500 to a "normalized" one at unit 100.

The application of learning curves is relevant to only the recurring portion of production costs and measures true learning only when all recurring costs have been converted to constant dollars. In the subsequent discussion of learning curves the term "cost" should be understood to refer to recurring production cost in constant dollars.

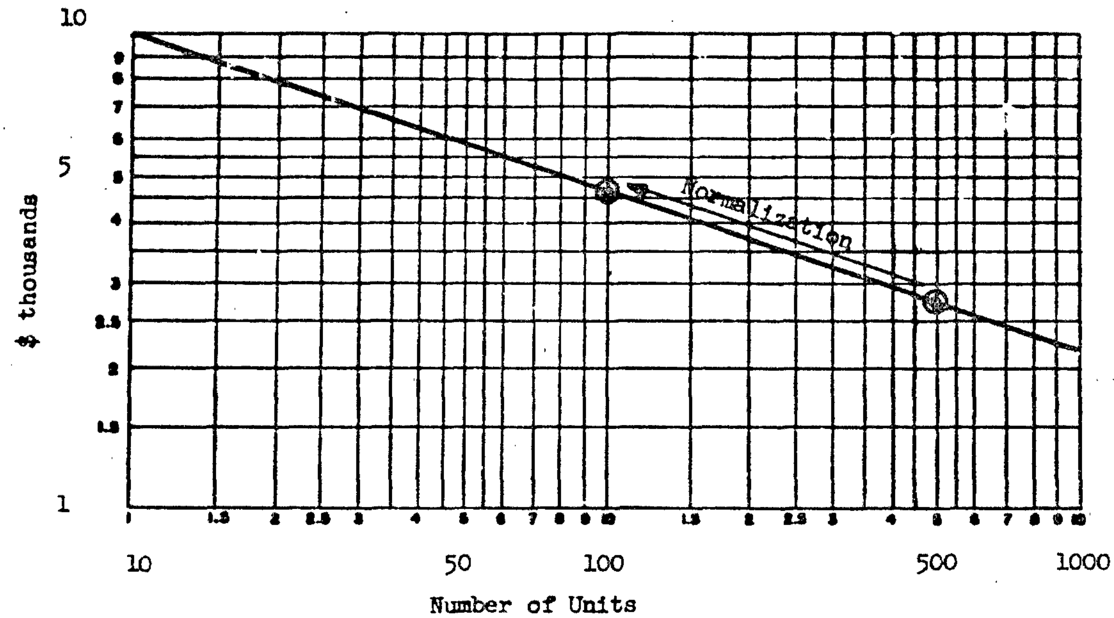

Fig. 3—Eighty Percent Cumulative Average Learning Curve

The two most familiar forms of learning curves assume that as the cumulative production quantity of units doubles the cost per unit declines by some constant percentage. One form treats the cost as the incremental or unit cost; the other treats it as the average cost for the cumulative number of units. Either formulation results in a function that is linear when plotted on logarithmic grids. When the incremental cost assumption is made, the form of learning curve is termed the "log-linear unit curve;" when the average cost assumption is made, it is known as the "log-linear cumulative average curve."

The complement of the constant percentage reduction, i.e., one minus the reduction, is referred to as the learning curve slope. Thus, an 80 percent slope means that the unit cost (or cumulative average cost) at quantity 200 will be equal to 80 percent of the unit cost (or cumulative

average cost) at quantity 100. Figure 3 shows an 80 percent curve (for specificity designated as log-linear in cumulative average form).

The algebraic expression for the log-linear unit curve is:

$$Y_i = aX_i^b$$

where Y_i = cost of i^{th} unit
a = cost of first unit
X_i = cumulative unit number
b = slope parameter.

The parameters a and b may be estimated directly by regression analysis if several values of Y and related values of X are known. However, this is usually not the case. Costs of hardware items are almost always accounted for in "lots" rather than in single units, and the average unit cost of a lot is not the cost at the arithmetic mean of the lot units. For example, if a lot includes cumulative quantities 101 through 200 at an average unit cost of $100, then the cost of unit 150 is not $100. This is because learning occurs within the lot itself.

The algebraic expression for the log-linear cumulative average curve is:

$$\overline{Y}_i = aX_i^b$$

where $\overline{Y}_i$ = cumulative average cost of i units
a = cost of first unit
X_i = cumulative unit number
b = slope parameter.

One advantage of using this formulation is that it is not necessary to calculate algebraic midpoints. The parameters a and b may be estimated by regression analysis provided that the cumulative average costs are known for several lots. However, in some cases the cost of one or more lots will not be known, and therefore it will be impossible to calculate the cumulative average cost for subsequent lots. When this occurs, the analyst may be forced to use the log-linear unit curve formulation.

Technical Characteristics. The problems associated with cost data are somewhat different from those associated with physical and performance data. The main cost problem is often one of securing a source, whereas that of technical characteristics frequently consists of reconciling conflicting values cited in several sources.

The succeeding paragraphs of this subsection address possible sources of technical characteristics problems and opportunities for meeting them. The presentation, like the corresponding one for costs, has been abstracted from the RAC CER Manual[14] (Part II, Chap. 2). The material, while most meaningful for those planning to develop CERs, contains much of broader applicability.

Problems of Definition. Once the appropriate physical and performance characteristics have been identified and the data sources selected, the most critical factor is to ensure that the characteristic values have the same meanings for all systems in the sample. When different sources are investigated, the analyst will frequently find that different values are given for apparently the same system characteristic. One of the possible reasons for these discrepancies is that the values might be based on different definitions. For example, there are many measures of the characteristic "horsepower." Horsepower rating would depend on such things as engine speed, type of fuel, whether the rating represents an instantaneous or sustained maximum, whether it is measured with or without accessories, whether it is measured at the flywheel or rear wheels, etc. Another possible reason is that the value for a characteristic may actually change over time because of modifications to the system. Whenever this occurs, the characteristic values should be associated with the appropriate costs.

Conversion of Measures. If consistently defined values cannot be found for all characteristics, the analyst can sometimes compute values that are comparable. Some performance characteristics, for example, are based on climactic conditions (e.g., 32°F or 60°F), and there may be standard formulas for converting all sample values to a common set of conditions. Other performance characteristics are direct functions of physical characteristics, and comparable values can be computed.

A common problem encountered in many CERs using weight as an explanatory variable is that the potential sample might contain systems manufactured from different types of material. This problem was encountered by WECOM in the development of manufacturing labor cost CERs for helicopter armament subsystems. In the pintle class of armament subsystems one model was constructed of steel whereas the others were constructed of aluminum. A comparability adjustment suitable for the purposes of CER development was made on the basis of relative weights (490 pounds per cubic foot of steel, 168 pounds per cubic foot of aluminum). Weight of the subsystem constructed of steel was adjusted by dividing this weight by 2.9167—the ratio of 490 to 168.[28]

The preceding paragraph addressed conversion of measures before CER development. An interesting example of conversion of measures applied to estimates from a derived CER is documented in a MUCOM cartridge CER report.[29] The derived MUCOM CER was based on ball-type cartridges with brass cases. The CER was used to estimate costs for the steel-cased Bushmaster round. To convert the CER estimate to one appropriate for steel rounds, brass/steel weight and cost differential factors were applied. After application of these adjustments (and one for inclusion of a tracer element in the Bushmaster round) the adjusted cost was compared to an independently prepared engineering estimate. The adjusted CER estimate differed from (exceeded) the engineering estimate by 10 percent.

Use of Proxies. Combinations of characteristics can sometimes be used as proxies for those that are not available or whose definitions are not consistent among sample systems. As a simple example, if the acquisition cost of a class of equipment is expected to vary directly with volume and volume data are not available, then cost should vary with the cube of a linear measurement provided that linear proportions

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[28]Patrick J. Gannon, "Cost Estimating Relationships for Aircraft Armament Subsystem Manufacturing Labor Cost," Technical Report AMSWE-CPE 71-11, US Army Weapons Command, Cost Analysis Division, Sep 71.

[29]Robert J. Brown, "A Cost Estimating Relationship for Ball Type Small Arms Ammunition," Report CA-M-71-1, US Army Munitions Command, Cost Analysis Division, Aug 71.

are relatively constant for different sizes of equipment in the class. Examples of use of proxies will be provided for CER investigations carried out at MUCOM and the Aviation Systems Command (AVSCOM).

At MUCOM the product of length times diameter squared was used as a candidate explanatory variable in various cartridge case CERs. This is a proxy for maximum volume and, to the extent that the cases are approximately cylindrical, is proportional to approximate case volume. This follows from the equation for volume of a cylinder:

$$v = \Pi \frac{ld^2}{4}$$

where v = volume

d = diameter

l = length.

Derived regressions based on the product, ld^2, have the factor of proportionality, $\frac{\Pi}{4}$, imbedded in the regression coefficient attached to the product term (see App E of Ref 14).

CERs developed at AVSCOM provide another example of the use of proxies (see Annex A1 of Ref 14). It was reasoned that the maintenance man hour requirements for helicopters should be related to the area swept by the rotor in a specified period of time, or:

$$A = \Pi \frac{D^2}{4} NR$$

where A = area swept per minute

D = rotor diameter

N = number of blades

R = number of rotations per minute.

The rotation (R) values were not known for all helicopters in the sample. However, it was known that the maximum velocity of the rotor tips, ΠDR, for all helicopters have nearly the same value. Area swept per minute was thus rewritten as:

$$A = \left(\frac{\Pi}{4} DR\right)\left(DN\right)$$

and finally to the approximation:

$$A \simeq KDN$$

where K is a constant and the other variables are defined as above.

The product variable, rotor diameter times number of blades (DN), was used as a proxy for area swept by the rotor per minute. The constant $\left(\frac{\Pi}{4}\right)$ is imbedded in the derived regression coefficient attached to the product term.

COST MODEL CONSIDERATIONS

A cost model can be defined as a set of relationships that operate on basic cost and quantity inputs and produce results expressed in terms of selected cost outputs. Every model has two essential functions — calculation and summarization. That is, in addition to generating numbers, a model also provides the framework for bringing together related results under "aggregate" output elements, thus facilitating subsequent analyses.

Cost models are of two broad types: manual (as in the DepotMAIDS studies) and automated (as in the CS_3 studies). The relative attractiveness of an automated vs a manual model depends on numerous factors such as the number of basic inputs, the complexity of calculations, the number of system alternatives, and the proposed uncertainty analyses. A model, whether manual or automated, must include all pertinent cost elements and variables, must uniquely identify each element and variable, and must establish the operations necessary for calculations.

Planning

Cost model planning must begin early in the economic analysis effort. Indeed, without engaging in some preliminary planning directed to the cost (or cost/benefit) model it is difficult to see how any purposive large-scale data gathering activities could be properly initiated. Detailed specifications are not required but the analyst must outline the types of costs to be reported (the chart of accounts), how the costs might be estimated (potential variables and estimating methods), and what factors are likely candidates for uncertainty analysis.

Development

It is difficult to distinguish between model planning and the early stages of model development. During the development phase the analyst continues the process of planning, but becomes increasingly specific about the cost elements to include in the model and the underlying

equations. Flexibility should be maintained in the early stages to permit incorporations of new study guidance or to adapt to available data. In analyses involving an automated model, programming should begin when it is judged that the model has sufficient permanence to make major rework unlikely.

Chart of Accounts. The cost model chart of accounts displays the breakdown of total system costs. For many analyses the traditional life cycle cost categories will serve as the first level breakdown. AR 37-13[7] prescribes a time-phased display of total system costs distributed in accordance with these categories. The cost categories by themselves are ordinarily too aggregative for purposes of computation and presentation. Therefore, a cost model chart of accounts will ordinarily contain one or more tiers of component cost elements for each cost category.

Life Cycle Framework. Life cycle costing has gained its wide acceptance because it provides a useful, comprehensive, and logical framework for developing and presenting costs. In this regard it should be noted that one cost-effectiveness study[30] ultimately accepted and used the life cycle cost structure following original doubts concerning its usefulness. The study rejected alternative structures which were based on system effectiveness attributes (dependability, availability, etc.) and type of cost calculation (cost-to-men, cost-to-performance-characteristic, etc.). The study concluded that "in light of the earlier trials at recategorizing cost elements, it appeared that the traditional [life cycle] categories were fairly good after all and should not be thrown out."

The life cycle framework is useful for two primary reasons. First, it distinguishes broad areas of cost that tend to differ with respect to time of realization. Figure 4 depicts the relationship between cost category and time. The framework is also useful because by and large the crucial determinants of cost differ for the three categories. Figure 5, with considerable oversimplification, illustrates this point.

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[30] Cheryle C. Smith et al, "Cost Effectiveness Methodology," TR-68-119: Part I, "Guidelines for System Life-Cycle Costing," TRW Systems Group, Jul 68.

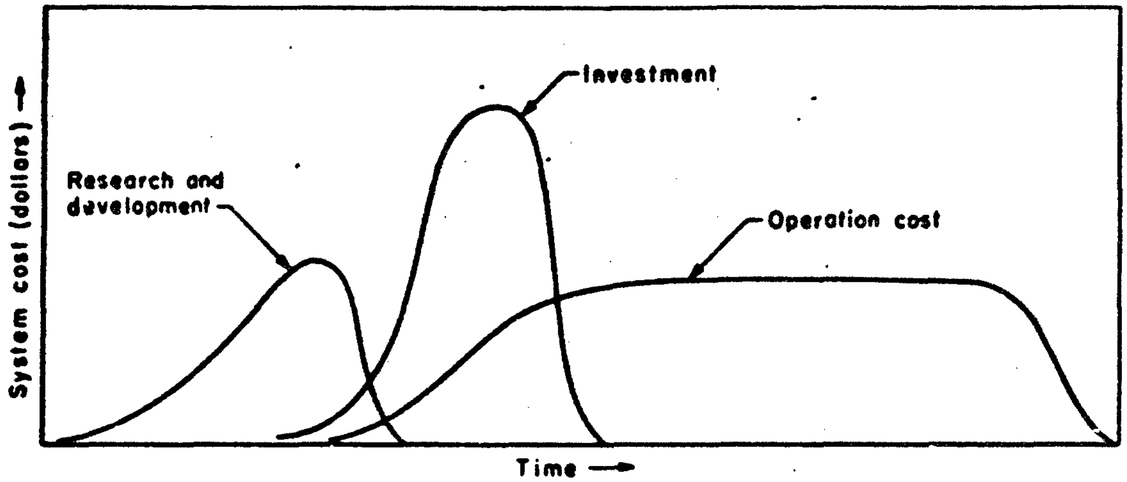

Fig. 4—Time Realization of Costs

Category	State-of-the-art advancement	Equipment and personnel quantities	Time period of analysis	Utilization rates
R & D	√			
Investment		√		
Operating		√	√	√

Fig. 5—Cost Categories and Major Determinants

Categories and Elements. R&D costs will not be pertinent in some analyses, and therefore the cost categories can be condensed to those of investment and operating. Analyses will have at least one alternative that involves investment, and alternatives in all analyses will give rise to operating costs.

Beyond the cost category level there is little standardization in the chart of accounts. Instead, the particular accounts are drafted to suit the characteristics of the system, the purpose of the study, and the nature of the available data. Figure 6 portrays an abbreviated chart of accounts. Although the figure is hypothetical, the cost element hierarchy shown might serve as part of the structure for an aircraft system or missile system cost model.

In general, there will be more calculations performed than there are cost categories and elements. The lowest level cost elements in Fig. 6 have been placed in broken lines to suggest that although major repair and overhaul costs might be calculated separately for parts and labor, only the grand total needs to be reported.

Cost Element Construction. The particulars of cost element construction are beyond the scope of this manual. Four guidelines, however, should be observed in selecting cost elements. These are discussed below.

First, all elements must be conceptually correct. That is, they must be relevant to a decision regarding choice among alternatives. Sunk costs must be excluded and all appropriate inputed costs for using existing assets must be included.

Second, the elements must be comprehensive and consistent. This means that all relevant costs are to be counted only once. The concept of cost relevancy is vital. In some studies total costs of alternatives are relevant. In others, perhaps only the differential costs from the base alternative are needed.

Third, the cost elements should be constructed as far as possible to parallel expected data information categories. This can lead to a substantial saving in processing and classifying data. The latest CS_3 study[12] (see Vol IV) provides an excellent example of adherence to this guideline. The ADP-oriented cost elements coincide with those in which costs are reported by ADP activities in accordance with AR 18-3.[25]

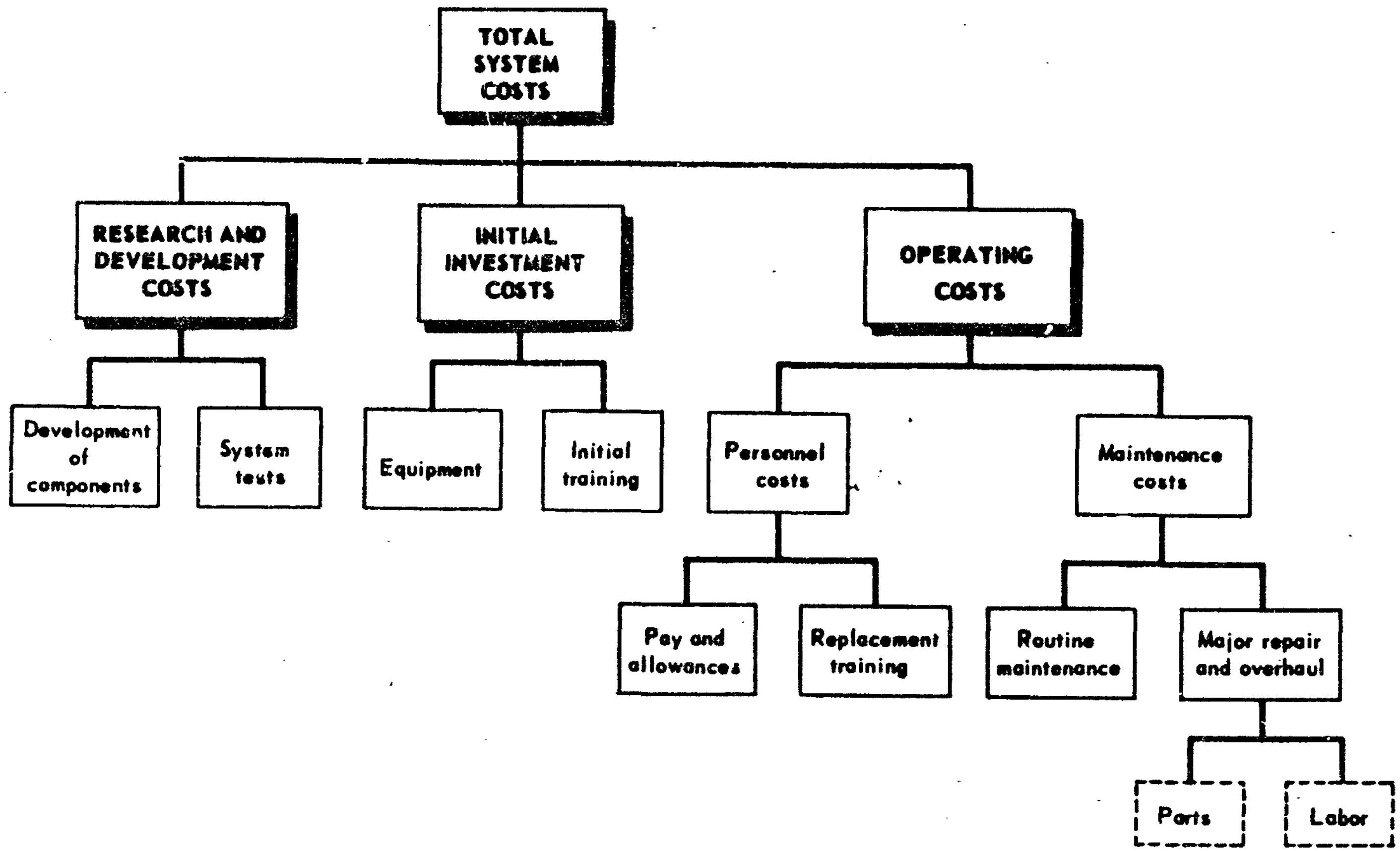

Fig. 6—Sample Chart of Accounts (Costs)

Finally, the cost elements should be ones conventionally used in studies. One of the purposes of the chart of accounts is to facilitate comparisons among cost element totals within individual studies and between different studies. This is furthered through the use of cost elements such as pay and allowances, training, equipment maintenance, and equipment replacement. Comparisons are hindered by inclusion of an element such as "Ecosystem costs," a major cost element employed in one cost model.[30]

Cost Element Equations. The first step in developing a cost element equation involves the identification of the basic cost generating activities or resources. Special costing considerations must then be taken into account. Where an automated cost model is being used, the analyst must decide whether to incorporate the considerations directly into the cost element equations or to introduce special routines elsewhere in the model. Succeeding paragraphs illustrate how the considerations of inheritance, discounting, and time-phasing might be introduced into hypothetical cost element equations.

Inheritance. The availability of inherited assets reduces the amount of new purchases required for a system. Equation (1) provides gross procurement costs, while Eq (1a) provides for costs exclusive of inheritance.

$$\text{Item A procurement cost} = \text{Item A unit cost} \times \text{quantity of A per system} \times \text{number of systems} \qquad (1)$$

$$\text{Item A procurement cost} = \text{Item A unit cost} \times [(\text{quantity of A per system} \times \text{number of systems}) - \text{quantity of A on-hand}] \qquad (1a)$$

The mathematics of Eq (1a) assumes no costs of refurbishment for the inherited assets. This assumption could be altered by the inclusion of a factor for refurbishment.

Discounting. Discounting is a technique for converting costs expected to be incurred at different periods to equivalent present value costs. This is done by adjusting the future cost (or benefit) for year and interest rate considerations. A standard rate of 10 percent is prescribed in AR 37-13[7] and a table of discount factors appropriate to this rate included for each year from one to twenty-five.

Equations (2) and (2a) exemplify the difference between calculation of undiscounted and discounted costs.

$$\text{Annual pay and allowances per system} = \text{Number of system military personnel} \times \text{average military pay and allowances} \quad (2)$$

$$\text{Pay and allowances per system in year N} = \text{Number of system military personnel} \times \text{average military pay and allowances} \times \text{discount factor for year N} \quad (2a)$$

The discount factors published in AR 37-13 are based on averages c' factors contained in standard present value tables. In particular, the rate for year N is equal to the simple arithmetic average of standard table values for year N - 1 and N. The averaging converts costs to a uniform stream over the year.

Time-phasing. The system objective quantity is generally reached over a period of time. During the period of buildup, total recurring costs will grow. This is because recurring costs are a function of the average number of systems in operation during the year. A less predictable pattern will be followed by one-time costs since these depend on the number of additional systems added during a year. Equations (3) and (3a) show the difference between a stable recurring cost and one that varies over time.

$$\text{Annual supplies cost (all systems)} = \text{Annual supplies cost per system} \times \text{number of systems} \quad (3)$$

$$\text{Supplies cost (all systems operating in year N)} = \text{Annual supplies cost per system} \times .5 \times (\text{no. of systems at end of year N} + \text{no. of systems at end of year N} - 1) \quad (3a)$$

The mathematics of equation (3a) provides costs <u>as if</u> system quantities were being added uniformly over a year. Where only system end year quantities are available, this is the simplest adequate formulation. The formulation may be used also in other applications because of its simplicity and approximate correctness.

<u>Checkout</u>

The calculation of the basic cost (and benefit) results is the most straightforward and mechanical part of economic analysis. Before the actual calculations begin, the set of equations, i.e., the model, should

be checked with a test case. This should be done for a manual model as well as for an automated model.

It is usually good practice to follow the test case with one or more live data sets to analyze the results for reasonableness. This procedure may result in discoveries of errors made earlier in developing cost factors, for example, failing to note that the basic data were quoted in thousands of dollars rather than dollars.

Where possible, the calculations underlying the study should be double checked. Accuracy is one concern. Another is the tendency of many readers to discount the credibility of the entire analysis on the basis of mathematical errors, even when the errors are not large enough to change the essential study results.

Errors of calculation are difficult to eliminate completely when using a manual model. The problem is made more acute where uncertainty analyses are involved, since several iterations may be necessary. When using an automated model for which the basic logic has been verified, errors of calculation reduce to errors of input. This is one of the advantages of a computerized model; errors can usually be detected by inspection of input listings.

Model Documentation

Any model used in an economic analysis must be set forth and explained sufficiently to permit tracing of operations from input to output. Word equations may suffice for manual models. For an example case see the DepotMAIDS case study in Vol IV.

If an automated model is utilized, it is recommended that a listing of the calculation portions of the program be provided. A variable dictionary containing definitions of the included variables should accompany the listing. None of the CS_3 studies provided any documentation of the type described above, and this led to considerable problems when attempting to track costs from one study to another (see CS_3 case study in Vol IV).

4 BENEFIT*

INTRODUCTION

The objective of this section is to discuss the basic considerations required to present decision makers with an orderly, comprehensive and meaningful display of all benefits expected for each alternative within the scope of the economic analysis under consideration. The benefits of each alternative should be expressed so that the decision maker is able to systematically compare the various alternatives of the economic analysis. Benefit in the context of this handbook is used as the overall term for returns (output, products, services, yields, worth).

The consistency and relevance of the benefits available must be carefully examined. An existing measure with which management is familiar has certain advantages in regard to ready acceptance as a benchmark, but it may not be relevant throughout the entire range of the study. The analyst should be as cautious both in accepting a benefit measure just because it's there and in introducing a new untried one that accommodates only an aspect of his study. The output information effort under DOD Instruction 7045.11[31] and DOD Directive 5010.15[32] should be studied.

*With some modification, this section was derived from the 2nd Edition of the DOD Economic Analysis Handbook.[1]

[31] Dept of Defense, "Improvement and Use of Output Information in the Department of Defense Programming, Planning, and Budgeting System," DODI 7045.11, 17 Dec 1970.

[32] Dept of Defense,"Defense Integrated Management Engineering System," DODD5010.15, 13 Jan 1972.

General aids in the pursuit of benefit measures are the following:

1. Use a systematic procedure to establish returns in order to minimize strictly subjective judgment.

2. Discover and record all the benefits, whether or not quantifiable, relevant for each of the alternatives developed in Item 2 of "The Process."

3. Express, if possible, the returns of each alternative in terms of a common denominator or a score.

4. Arrange returns according to some hierrarchy of values if a common denominator is not available.

The remaining part of this section will outline how to determine the benefits of an option or alternative under consideration in an economic analysis. Given the state of the art, the following overall methodological steps will be used to guide the analyst:

Step I - Determine, list and define relevant benefits.

Step II - Establish sources of information for benefit determination.

Step III - Collect and display information for benefit determination.

Step IV - Summarize, evaluate and present benefit determination for alternatives of the economic analysis.

PROCEDURES

Step 1 - Determine and Define the Benefits Relevant for Each of the Alternatives of the Economic Analysis

1. Determine and list the benefits of each alternative—whether the benefit is thought to be potentially quantifiable or not quantifiable. List all benefits which may illuminate the economic analysis alternatives. It is quite possible that some of the benefits listed in this first attempt will eventually be discarded and others becoming evident further in the analysis will be added to the list. For instance, if one method causes ten items to be produced and only two are needed, the greater productive capacity of this system may not be a plus factor. Other considerations may arise such as the availability of storage space, the cost of storage, obsolescence, etc.

2. Define each benefit in relation to its respective alternative in the economic analysis. It is to be noted that any point in the Benefit Determination Procedure, new or previously unrecoganized evidence may require a reassessment of the benefits listed up to that point.

During this process consideration should be given to the level of decision of the economic analysis. For example, assume that in a five-man warehouse at an installation, spare parts are stored on seven shelves and it has been proposed that decreasing the layers of vertical shelving will obtain greater warehouse efficiency. Instead of having seven shelves, the items will be stored on five shelves so that all items will be accessible without using ladders (ladder is now used when pulling material from the two top shelves). In this case, the decision could be made by the local operating official and external benefits related to economic effects on the community (if any) would not be germane. However, benefits related to customer service, employee morale, safety, etc., should be considered.

However, if the investment is a large one, such as whether or not to consolidate field activities or buy special equipment, the decision may be made at the Service level (and in some cases, probably, at the OSD level). In such cases, benefit determination related to the economics of the community might be one of the determinants for selecting a particular alternative.

Each situation must be dealt with within the context of the total economic analysis under study.

There is no check list available which can be used to ascertain that all output returns for an alternative of an economic analysis have been included in the benefit determination, and that all are valid for the particular situation. However, in order to assist the analyst in selecting benefits germane to the study and, hopefully, in excluding spuriously related and nonsignificant information for the decision maker, characteristics such as the following could be reviewed when listing and defining benefits.

Discreteness. Is the benefit clearly and concisely identifiable from all of the other benefits? Does it overlap with any other measure? Is it duplicated? Maintain as separate an entity as is possible.

Quantification. Is the benefit directly/indirectly measureable using valid techniques available from the various disciplines used in analysis? If not, can some method for comparability be used? If quantification is not possible, can other techniques such as ranking, etc., be used for decision purposes? Quantification is by no means essential for output information to be useful for analytical purposes, although precision and specificity are needed to the greatest feasible degree.

Discriminative. Is the benefit related to the alternative of the economic analysis? Is it discriminating in relation to the objective of the decision maker? Is it spuriously related to the purposes of the decision and should therefore be excluded?

Also, it might be found that the benefits expected of any alternative may fall into various "categories" depending on the kind of program, systems, operation, organization, etc., that has been submitted for economic analysis. Terminology used for these categories is generally descriptive of the benefits included. These are not intended as definitive, but as guides to the analyst in the effort to include all benefits related to an alternative. It also should be cautioned that the list is not intended to be all inclusive; it is only illustrative of some of the types of benefit categories that could be applicable depending on the problem. Some of the categories under which benefits appear are:

1. Production. Number of commodities or items produced for each alternative. For example, number of meals served, hours flown, components manufactured. This could be related to comparable time periods of the economic analysis (as in productivity).

2. Productivity. (related to staffing benefits) number of items per manhour, volume output related to manhours.

3. Operating Efficiency. At what rate does the system consume resources to achieve its output? For example, miles per gallon, copies per kilowatt hour, mean days per shipment.

4. Reliability. This describes the system in terms of its probable failure rate. Useful measures may be mean-time-between-failure, the number of service calls per year, percent refusals per warehouse requests.

5. Accuracy. What is error rate? Measure errors per operating time period. Number of errors per card punched, errors per hundred records, errors per 100 items produced, etc.

6. Maintainability/Controllability. Has adequate human engineering been performed? Is the system compatible with adequately trained crew members? When the system does fail, is it difficult to repair because of poor accessability? A useful measure could be based on the average man-hours necessary for repairs over a given time period, i.e., downtime, or the crew rate necessary to control and maintain the system.

7. Manageability. Consider how the workload of the organization will be affected by increased or decreased supervision or inspection time as a result of the system. Man-days could be used as a measure; difference in kind of personnel might be a factor as well as availability of type needed.

8. Integrability. Consider how the workload and product of the organization will be affected by the changes necessitated in modification of existing facilities or equipment, technical data requirements, initial personnel training, warehouse space for raw goods or parts storage, etc.

9. Availability. When can each system be delivered/implemented; when is it needed to meet proposed output schedules? What is the lead time for spare parts delivery?

10. Service Life. Consider how long the proposed system will affect the organization's workload or output. What about obsolescence?

11. Quality. Will a better quality product/service be obtained? Could quality be graded, thus measurable? If not, a description of improvement could be given. What is the impact of the varied quality?

12. Acceptability. Consider the alternative in terms of whether it may interfere with the operation of parallel organizations or the operation of prerogatives of higher echelon organizations.

13. Ecology. Consider the ecological aspects of each alternative. What are the current legislative requirements?

14. Economic. Consider employment benefits, DoD small business obligations, economically depressed area relationships, legislative requirements.

15. <u>Morale</u>. Employee morale. This could be measured by an opinion sample survey.

16. <u>Safety</u>. Number of accidents, hazards involved.

17. <u>Security</u>. Is security built in? Will more precautions be needed? More guards? Are thefts more likely?

Pertinent benefit categories will become evident as the analysis of the alternatives is performed. The benefits will be defined/described in accordance with the requirements of each alternative under review.

<u>Step 2 - Determine Sources of Information for Benefits Determination</u>

Separate the Benefits defined in Step 1 into two lists as follows:

<u>List 1</u>. Benefits where Back-up Information is Available.

Benefits for which information in usable form is easily obtainable. Next to each benefit listed, indicate source of information, in what form it is available. Also include in general terms the proposed methodology for gathering the needed information and the feasibility of doing so. Should the analyst decide that obtaining the needed information is impractical, for whatever reason, he should be able to support his position. This step applies to benefits which may be quantifiable as well as for those which are not quantifiable. It is best to obtain the maximum amount of information in estimating parameters. However, this may not always be feasible.

For example, if in Step 1 "Production of an Item" is listed, the data available should be checked to see if there are weeks, years, etc., of production records with data which could be used for actual production and estimating purposes when valid statistical or other analytical techniques are used. If the immediate organization does not have such information, is it available for a comparable organization? Is prototype data available, etc. The statistician, mathematician, industrial engineer, etc. will be helpful in determining whether there are techniques available in the relevant disciplines that can be applied to substantive information in order to obtain the benefit determination needed for the economic analysis. (Applying various techniques to data already in the system could preclude the cost and time needed to gather additional data.)

For benefits not quantifiable by ranking, rating, or related methods, a list of appropriate available and reliable sources for narrative detail should be compiled.

List 2. Benefits for Which Back-up Information is not Available.

For the remaining benefits, or those for which no information sources have been readily identified, the analyst will have to do further research in order to obtain information on benefits. Additional research might include activities such as a 100 percent survey of relevant data, a sample survey of less than 100 percent, field trips to visit experts, visits to specialized libraries, and interviews with public agencies or private firms. The specific circumstances will decide the process.

Examples of benefits for which information is not readily available are morale of personnel, safety of an operation, etc. In these instances, a statistical sampling can be used to produce data for the system and these data can be used as benchmark statistics for the related alternatives and for projection purposes. For a weapons system where data may not be available, a combination of parts of existing systems may serve the same purpose.

With the completion of Step 2 of this procedure, the analyst should have:

a. Identified and defined or described the benefits resulting from each alternative required in the particular economic analysis.

b. Sources of information and/or methods for obtaining the information for each benefit.

Step 3 - Collection of Information for Benefit Determination

1. Organize the method for collecting information for each benefit, collect the applicable data, and record the information for each alternative of the economic analysis.

2. It must be emphasized that both the subject matter specialist and the individual knowledgeable in the disciplines concerned with formulating quantifiable and nonquantifiable outputs for analysis purposes must cooperate if adequate usable benefit determinations are to be established.

3. The information collected can be recorded by listing the information for each benefit in tabular format which is similar to the display in Table 2.

After Step 3 has been completed, it is beneficial for the analyst, to review what has been done to see whether benefits should be added/deleted or whether more relevant yardsticks for the associated benefits could be designated.

Summary - Evaluation and Presentation of Benefits

In order for benefit determination to be of value for the decision maker, comparative visibility of the benefits of each alternative is necessary. A generalized format is presented in Tables 3 and 4. The exact method of comparison and the tools and techniques to be used must be left to the analyst in conjunction with the subject matter and professional analytical personnel since proper "weighing," quantitative and nonquantitative comparisons and overall scoring of system dimensions will vary with different systems, organizations, programs, etc. being studied in the economic analysis.

Many techniques are available for comparing quantifiable benefits such as graphic analysis, regression analysis, indexing, decision theory, marginal analysis, ratios, linear programming, mathematical and economic statistical modeling. Nonquantifiable benefits may be analyzed by using nonparametric statistical techniques. A possible technique for weighing benefits might be a polling technique such as the Delphi method.

Benefits should be arranged in the order of significance of each benefit to the problem objective. Then, where possible, benefits should be combined to give a composite score for each alternative. In some cases, it may be possible to calculate a score for the total alternative directly if data are in the same units. In any event, such consolidation will assist in the decision making process since it reduces some of the detail. For example, in order to measure the benefit of different warehouse processes, it may be feasible to measure the warehouse's receiving and storing functions. Since receiving is recorded in line items and storing in measurement tons, it is possible to combine the two using a weighted index with respective man-hours for each function as

Table 2

BENEFITS IN TABULAR FORM

Benefits	Mode of appraisal (whether or not quantified)	Alt. I Years of alternative life				Alt. II Years of alternative life				Alt. III
		1	2	3	4	1	2	3	4	Etc.
Production	Items per hour									
Customer satisfaction	Percent served on time									
Safety	No. of accidents per employee									
Morale	Narrative and/or ranking (reaction of community to system planned) Good (1). Poor (2). Indifferent (3).									
Quality	Errors per record									

Table 3

SAMPLES OF BENEFIT DETERMINATION DISPLAYS

Benefits (In order of significance)	Mode of appraisal and/or measurement	Alternatives	
		I All years	II All years
A. Quantifiable benefits			
1. Productivity	No. of line items per manhour	100	50
2. Accuracy in operation	Stockpicker errors per 1000 line items issued	12	6
3. Customer satisfaction	Percent shipped on time	70%	90%
4. Safety	Employee accidents per year	3	1
(Composite Score - if possible)			
B. Nonquantifiable			
1. Morale	Concensus of employee opinions	Climbing ladders is not desirable; wastes energy.	Desirable since material easier to reach and energy conserved, less tiring.

Table 4

SAMPLES OF BENEFIT DETERMINATION DISPLAYS

Benefit (In order of significance)	Mode of appraisal	* Alt. I all years	*Alt. II all years	*Alt. III all years
A. Quantifiable				
1. Start of delivery of product	Contract specification	In process 10/71	12/71	12/71
2. Production	Units per mo.	100	75	150
3. Durability	Temp. opera-tirg range	40-80 deg.	40-80 deg.	50-75 deg.
4. Maintenance	Av. maint. manhours per repair (con-tract specs)	15	10	10
(Composite Score - if possible)				
B. Nonquantifiable				
1. Economic impact	Expert judg-ment	Retention will maintain employ-ment in area. Otherwise other work will be needed.	No need for new work to maintain employment which is at healthy level.	Economically depressed area. Employment
2. Quality control (inspection)	Contract specification	All government inspectors	Contractor inspected, followed by limited Govern-ment inspection.	Total Contractors inspected.

*If benefit data change with year, detail for each year; otherwise give total length of life for each alternative.

weights. Alternative I warehouse benefit would then be equated with base 100 and variation from this could be on par, better, or worse for other alternatives depending on the weighted index calculated from the estimated or actual data.

Another method of composite scoring would be to convert actual output to some common factor such as dollars. In so doing, a portion of the worth of the combined alternative benefits is implicitly assigned to each benefit. For instance, the expected yearly repair cost can be predicted on the basis of the mean time-between-failure and average maintenance downtime for each alternative. In converting to dollars, care should be taken in the mathematical relationship between the cost side of each alternative and the cost conversions on the output/benefit side of the equation.

The most significant problem in determining overall technical and logistical competence of a system is deciding upon the proper weights to be given to the various benefits. When objective inherent weights of the system, such as relative manhours, dollars, etcs., are not available, the criteria for weighting should be based on how much each contributes to the accomplishment of problem requirements, i.e., the economic analysis problem under consideration.

In situations where it is difficult to project benefits and/or to compute measures, it is desirable to provide as much useful information as possible to enable a decision to be made as to which alternative yields the most benefits.

A composite total worth or value of a system is not always possible by objective quantitative scoring or weighting. The comparison format, with composites as subtotals of individual benefit statistics, will allow for appraisal by experts and final review by the decision maker.

5 UNCERTAINTY

Uncertainty is present in virtually all decision making activities. Economic analysis with its emphasis on assessment of alternatives in the future is an activity with a high degree of uncertainty. Often the costs and the benefits for different alternatives will differ significantly in terms of "certainty" of outcome. This is especially likely to be the case when one of the alternatives is an existing system or project.

Uncertainty is frequently distinguished from risk. The distinction involves a delineation between subjective and objective probabilities.

Risk prevails in situations where enough is known to permit assignment of objectively determined probabilities to all possible outcomes. The objective determination can be based either on theoretical considerations (die tossing or coin flipping experiments qualify) or on substantial and impartial empirical evidence (the cornerstone of production and acceptance quality control applications). Uncertainty exists where any assignment of probabilities is limited to subjective judgment.

The following excerpt distinguishes between risk and uncertainty:[33]

> An example of a risk is a gambler making a bet that he will draw a red ball from an urn containing 5 red balls and 10 white balls. The possible outcomes are known, and the probabilities are 1/3 for a red ball and 2/3 for a white ball. An example of uncertainty is making the same bet where the number of red balls and the number of white balls are unknown. In this case, all that can be said[objectively] about the outcome is that a red ball or a white ball will be drawn.

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[33] ARINC Research Corporation, "Guidebook for Systems Analysis/Cost Effectiveness," Mar 69.

As Fisher[34] has stated, objective probabilities for critical variables are generally not available to the military systems analyst. Resultant studies (including economic analyses), therefore, overwhelmingly address situations containing uncertainty rather than risk. The topics that are discussed in this section are related primarily to uncertainty. These are:

- Empirical analyses of uncertainty
- Need for analysis
- Approaches to uncertainty
- Documentation

EMPIRICAL ANALYSES OF UNCERTAINTY

A considerable number of studies, most of them produced by the RAND Corporation, have empirically addressed the problem of uncertainty. The studies, with the exception of one by Fisk,[35] have been concerned with identifying the factors that explain the variance between actual and estimated costs. Typically the investigations have been limited to military hardware production costs, particularly to those for aircraft and missiles. The results of three studies and their methodological approaches will be discussed.

Fisher.[36] Variations between actual and estimated costs arise partly because of differences in projected and actual production quantities and partly because of general price movements since the time of estimate. Fisher isolates the factors accounting for the variation between actual and estimated costs. These factors are adjusted for price level and production quantity influences and are segmented into two classes—requirements uncertainty and estimating uncertainty. Requirements uncertainty derives from changes in system performance and physical characteristics

[34]G. H. Fisher, "Cost Considerations in Systems Analysis," R-490-ASD, The RAND Corporation, Dec 70.

[35]Donald M. Fisk, "Estimates of Aircraft Characteristics with Some Implications for Cost Analysis," in Proceedings of the Third Annual Department of Defense Cost Research Symposium, 13-14 May 68, Vol I, Tab A.

[36]G. H. Fisher, "The Problem of Uncertainty," Chap. VI of J. P. Large (ed), Concepts and Procedures of Cost Analysis, RM-3589-PR, The RAND Corporation, June 63.

over the development cycle. Estimating uncertainty derives from the fact that the estimating tools and the data on which they are based are imperfect.

Fisher utilized several pre-1960 studies as the raw materials for his investigation. These studies had shown that on the average actual costs (or late estimates) might be in the neighborhood of 200 percent higher than early estimates, even when adjustments had been made for price level and production quantity changes. The estimates not only showed considerable dispersion from "actuals" but also displayed a consistent bias. Actuals invariably tended to be greater than estimates.

The basic studies not only recognized the split between requirements and estimating uncertainty, but anticipated Fisher's conclusion that the former overshadowed the latter in explaining the differences between actual and estimated costs. The earlier studies did this via qualitative conclusions. Fisher's contribution was that of providing quantitative measures.

This was done by referring to cost studies that had investigated fully designed items produced under standardized methods. Requirements uncertainty for such items would be minimal, and any reported differences between cost estimates and actuals would primarily represent the results of estimating errors.

Fisher concluded on the basis of the evidence at hand—briefly summarized in his study—that it was reasonable to conclude "that variation in cost estimates attributable purely to cost-estimating uncertainty might average 20-30 percent." Put another way, the analysis suggests that on the average requirements uncertainty is three to four times as great a contributor to cost variation as estimating uncertainty.

Harman and Henrichsen.[37] Harman and Henrichsen proceed from the observation that actual costs generally tend to be greater than estimates to an analysis of whether the estimating process itself showed any improvement from the 1950's to the 1960's. Ratios of actual to estimated

[37]Alvin J. Harman and Susan Henrichsen, "A Methodology for Cost Factor Comparison and Prediction," RM-6269-ARPA, the RAND Corporation, Aug 70.

costs—suitably adjusted for price level and production quantity differences—were investigated separately for the two decades via regression analysis. A measure of program development length and one for development effort were employed as explanatory variables in various regression forms. Fisher's dichotomy between requirements uncertainty and estimating uncertainty was implicitly accepted although no attempt was made to separately measure each part.

The study analysis is too complex to permit a concise summary. One major result bears repeating, however, because it provides indirect evidence that Fisher's estimate of an average 200 percent variation between actual and estimated costs, which was based on major military hardware production during the 1950's, may still hold. Harman and Henrichsen report that "none of the structures explored indicates a significant difference between the 1950s and 1960s in the ability of the 'system acquisition process' to estimate costs accurately or avoid actual cost overruns for a given development program."

Fisk.[34] Fisk provides the results of an analysis into the uncertainty of estimates for three technical characteristics of fixed-wing aircraft. The study consists of three parts. The first shows how the estimates of maximum speed, gross takeoff weight, and maximum thrust vary from eventual actuals according to when in the development cycle the estimates are made. The second part uses technical specifications for a hypothetical bomber and RAND costing methodology to illustrate how technical specification errors become translated to costing errors. The final part discusses some of the broad potential implications suggested by the limited analysis.

Figure 7 shows a scatter diagram of the percentage errors of speed estimates against their dates of estimate, date of estimate being normalized to number of months from initial delivery. Diagram construction can be made clear by reference to the circled observation. This observation represents a case where a speed estimate "was made 76 months prior to the first delivery of the aircraft. It shows the estimated speed to be 33% less than the actual. In this particular instance the speed was estimated at 800 knots and the actual speed was 1195 knots."

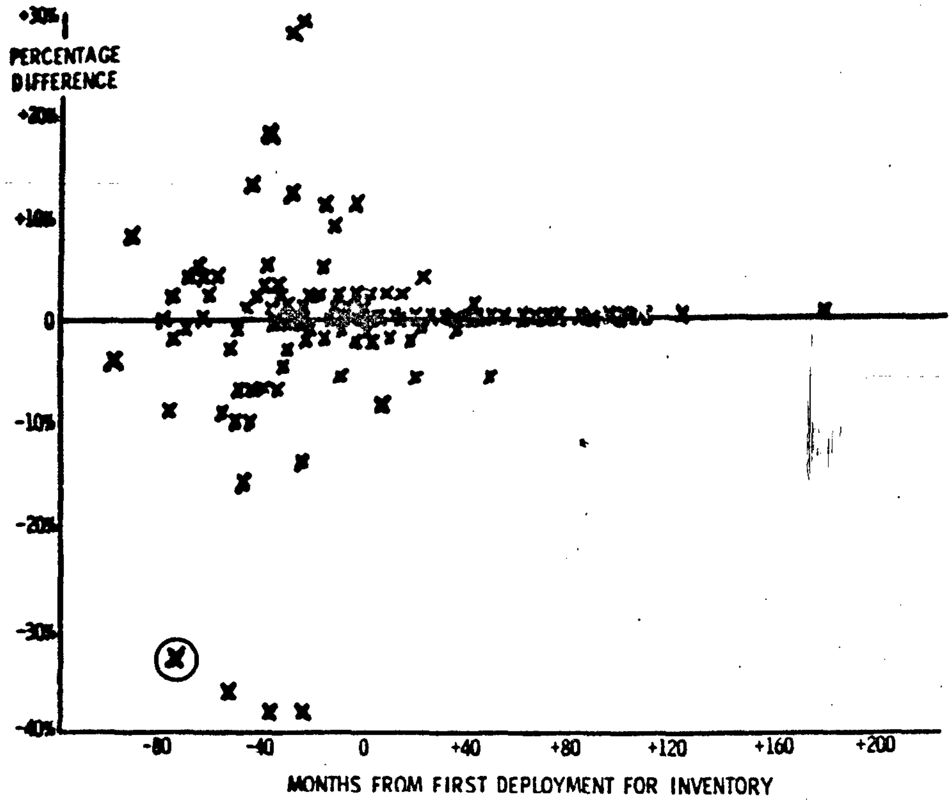

Fig. 7—Estimates of Maximum Speed

Two conclusions can be drawn from Fig. 7. First, estimates of maximum speed that are made late in the development cycle tend to be considerably more accurate than those made early. This is an important result, although far from surprising. Second, errors in speed estimates do not exhibit any strong bias. That is, unlike the case for cost estimates, errors in speed estimates are just about as likely to involve overestimates as underestimates.

Figure 8 depicts the relationship between estimating accuracy and time of estimate for gross takeoff weight. A trend line very similar to that shown in Fig. 8 was found to be appropriate also for maximum thrust, with thrust showing slightly more dispersion around the trend than weight. Estimates of gross takeoff weight and maximum thrust show improvement in accuracy as the time of estimate moves from the early stages of development towards the date of first deployment. In this regard the estimates

for these characteristics parallel those for maximum speed. As can be seen from Fig. 8, the estimates for weight tend to be biased towards underestimating. In this regard weight (and thrust) estimates are more akin to cost than to speed estimates.

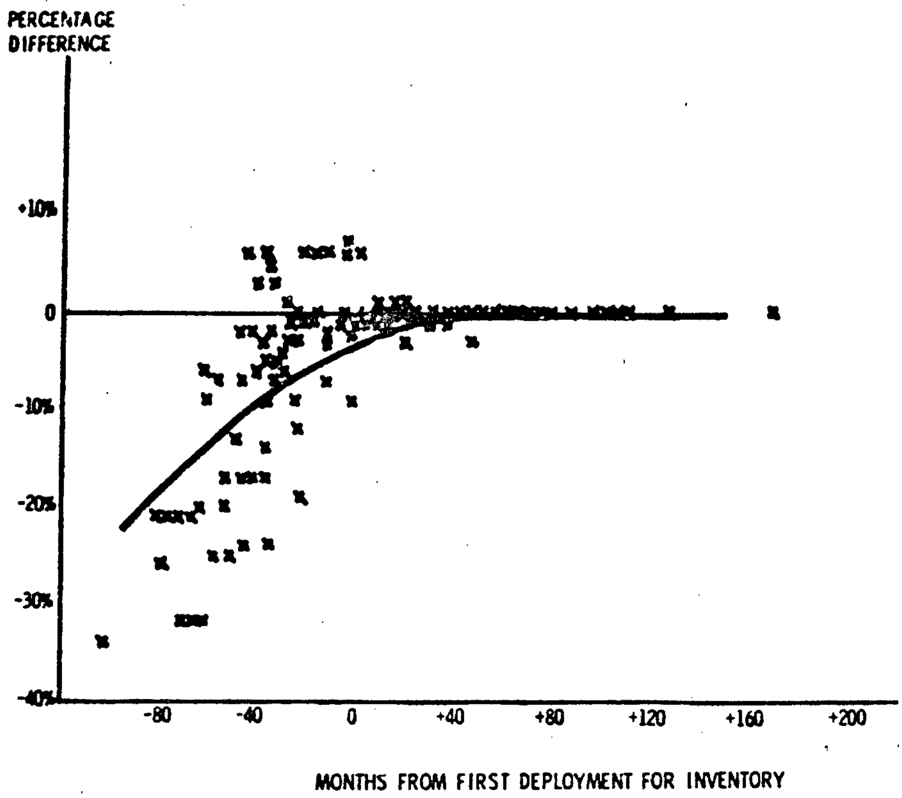

Fig. 8—Estimates of Gross Takeoff Weight

The central message of Fisk's study, at least from the perspective of the present handbook, follows:

> If input errors are as large as the example of the B(X) [a hypothetical bomber used for illustration purposes] suggests, the cost analyst should worry about inputs as well as models and outputs. The development and use of cost estimating relationships illustrates this point. Over the past several years considerable time has been spent analyzing and selecting relationships of this type. Often excruciating effort has

been devoted to selecting the variables and relationships which best explain changes in costs. So far as is known no effort has been devoted to examining the effect of input errors on errors in costs. An examination of some of the more important cost estimating relationships used today suggests that greater errors exist in the inputs than in the estimating relationships.

NEED FOR ANALYSIS

The reason that uncertainty must be faced directly and analyzed is that the results of such analysis can impact on the choice among alternatives. It is not enough to present the decision maker with a set of alternatives whose costs and benefits are based on "most likely" factors and assumptions. The decision maker needs to be informed about the robustness of the results. That is, how well the rankings of the alternatives hold up under reasonable changes to factors and assumptions.

As the previous paragraph suggests, the analyst must focus on the sources of uncertainty that are most likely to have implications on the ranking of alternatives. A first step is to identify the areas in which the alternatives differ significantly from one another. Even though a particular element of cost or benefit may be surrounded with considerable uncertainty, the analyst may be able to give it low priority when the element appears to affect all alternatives to approximately the same extent.

Requirements uncertainty and estimating uncertainty constitute parts of the overall problem of uncertainty, but only parts. In addition, time-phased deployments, operating rates, support considerations and general political and economic considerations will frequently be important and should be analyzed. Other areas may be important to a particular study. The ones cited are intended solely as examples.

Uncertainty analyses can be very time-consuming. In addition to the obvious increased calculation load, they create the need for additional data and require the various results to be compared and interpreted. The amount of analysis to apply ultimately resolves to judgment on the part of the analyst. Often the availability or planned development of an automated cost-benefit model will be an important determinant in the final judgment.

APPROACHES TO UNCERTAINTY

Four traditional approaches to the problems of uncertainty are characterized in this subsection. These constitute the following types of analysis:

- A fortiori
- Sensitivity
- Contingency
- Statistical uncertainty

A Fortiori Analysis

A fortiori analysis involves deliberate attempts to formulate assumptions that tend to uniformly favor or disfavor a particular alternative. The rationale is that if the assumptions uniformly favor (disfavor) an alternative and the alternative still does not (does) rank above other alternatives, then any other set of assumptions would only tend to reduce (enhance) the alternative's relative ranking. When the a fortiori approach is used, assumptions typically are made in such a way as to favor the existing system (status quo).

The a fortiori approach is refreshing in the sense that it appears to be a tool that is used more frequently in economic analyses than talked about. Volume IV provides examples of a fortiori analysis conducted on CS3 and DepotMAIDS. Brief abstracts from the most recent studies of these systems exhibit appreciation of the basic a fortiori logic:

> CS3-------------"A basic tenet guiding this update has been a desire to inspire confidence in the decision maker by enhancing the credibility of the result. For that reason, every effort has been made to make the most conservative assumptions. Where a question of fact existed or a simplification was necessary, the issue was always resolved in favor of the present (baseline) system."[12]

> DepotMAIDS------"In all cases the most conservative estimates have been used to compute savings; therefore, the above savings represent the minimum achievable."[10]

Sensitivity Analysis

Sensitivity analysis is used to address the mathematical or quantitative aspects of uncertainty that are associated directly with the system parameters. It considers factor values under different assumptions

in order to ascertain the range of impact that changes in quantitative data have on the costs and benefits of each alternative. Although costs and benefits may turn out to be insensitive to wide variations in certain factors, slight variations in others may result in highly volatile results.

Sensitivity analysis involves iteration of calculations using different quantitative values for the variables of interest. In one approach the analysis is initiated by formulating pessimistic, optimistic, and most likely estimates of values for the selected sensitivity variables. Calculations are then performed using the most likely set of estimates. The results constitute a common base for comparing results obtained from any other combination of estimates. Sensitivity analysis is discussed in more detail in App B.

Contingency Analysis

Contingency analysis is designed to cope with significant uncertainties of a qualitative nature much as sensitivity analysis does for those that are quantitative. Contingency analysis does not attempt to indicate the effect on study results of alternative values for a limited set of system parameters. Instead, it addresses the effect on results of various broad environmental conditions such as peace vs war, decreased (or increased) size of the Army, continuation of current standards against pollution vs institution of more stringent ones.

Contingency analysis, like sensitivity analysis, is a repetitive process. A base set of environmental conditions is established, results calculated, and the effects of changing the conditions assessed by repeating calculations using new combinations of conditions. Such changes can have a marked impact on the ranking of alternatives. For example, one alternative for a supply system might easily be the preferred alternative in cost-benefit terms when the system is assumed to support operations at a low activity level; at higher levels of operation, however, the alternative might become relatively unattractive.

There appears to be a natural tendency to assign probabilities to contingencies so that those of low probability can be ignored or the effects of several contingencies weighed and combined into more general ones. Such assignments are based ultimately on subjective judgments.

Subjective assessments taken on added credibility to users of a study when it can be demonstrated that they were derived by orderly and logical procedures. For this reason, the Delphi technique described in App D may prove useful.

As a rule, the analyst should attempt to make firm plans for contingency analysis earlier than for sensitivity analysis. Where the contingencies involve substantially different assumptions of the "real world," the analysis of these contingencies may approximate the performance of separate studies.

Statistical Uncertainty

CER Statistics. A CER by itself provides only the means for estimating the values of the cost variable given values for one or more explantory variables. A number of regression-related statistics and associated tests of statistics are used to measure how good an estimator the regression is on an overall basis and how much credence to place on the empirical values of individual constants. Detailed discussion is provided in "Regression Analysis" in App C. The present material is based on Ref 14.

The coefficient of determination is a measure of the relative worth of a CER. The coefficient is a number between 0 and 1 that indicates the percent of total variation of the dependent variable in the CER sample that is explained by the CER. Alternatively, the coefficient indicates the average degree of improvement in estimating the magnitudes of the dependent variable by taking into account the magnitudes of the independent or explanatory variable(s).

A CER provides a point estimate of the dependent variable (cost) for each set of values of the independent variables. While the point estimate is the best predictor in a statistical sense, it does not provide a measure of the uncertainty associated with the estimate. Confidence intervals may be constituted which provide a measure of the uncertainty associated with the point estimate. Figure 9 depicts a 90 percent confidence interval for a two variable regression equation. The confidence interval provides a range of values of the dependent value which can be associated with each value of the independent variable. The interpretation of the range is as follows: "In a large number of applications, the

two costs will fall between the upper level and the lower level in 90 percent of the applications."

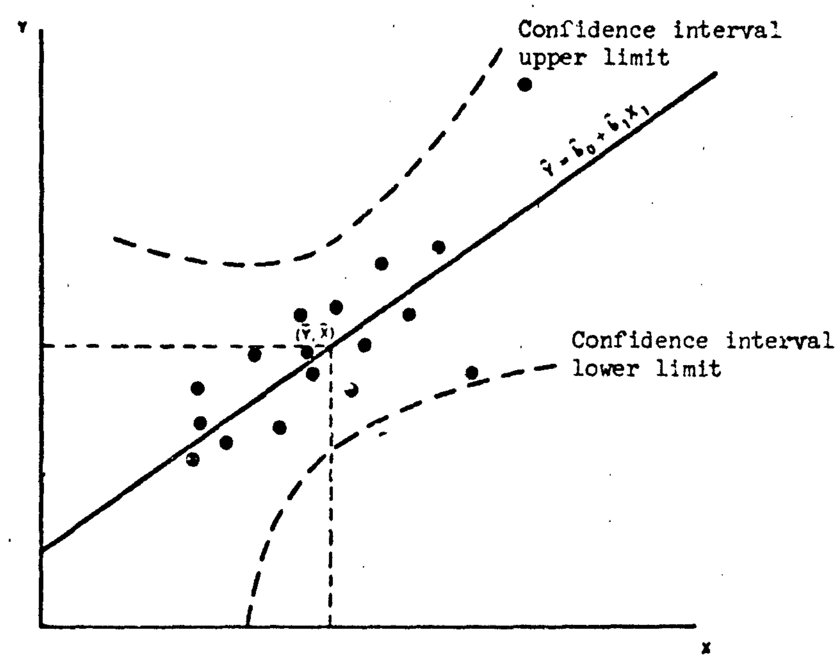

Fig. 9—Ninety Percent Confidence Intervals: Simple Regression

It is to be noted that the confidence levels have the narrowest range at the mean of the independent variable ($\bar{X}$) and as predictions are made further from the mean, the level of confidence decreases for an absolute variation from the CER or alternatively the range or interval for a given percentage level increases. A 95 percent confidence interval would encompass a wider range of values than the 90 percent interval, and as expected, an 80 percent confidence interval would encompass a narrower range.

Computer Programs. Several computer programs have been written to address the problem of system cost uncertainty from a probabilistic viewpoint. Most of the models involve estimating the total system cost and the associated probability through application of Monte Carlo analysis of component cost estimates. Models developed by Schlenker[38] and Schaefer[39] are representative.

The central features of the cost uncertainty computer models have been succinctly described by Husic.[40] Each model requires "expression of input estimates as probability distributions reflecting uncertainty [and] cost equations pertinent to the particular model." Each model generates "frequency distributions for cost elements and aggregations [together with] statistical measures that illustrate the nature and magnitude of the system cost uncertainty."

Few economic analyses will require the use of special computer programs of the type described above. Discussion has been presented for the sake of completeness and for the occasional problem that may benefit from the use of such a program. In this regard it should be noted that the Schaefer model[39] was adapted and used in a life cycle cost study for the utility tactical transport aircraft system (UTTAS). The circumstances surrounding the UTTAS study were ideal for the use of a cost uncertainty model. A high cost system was being addressed at a time when the system configuration was far from fixed; in fact, the study preceded approval of the qualitative materiel requirement.

[38] George Schlenker, "An Analytical Estimation of System Cost Uncertainty," Technical Note 67-3, US Army Weapons Command, Sep 67.

[39] Donald F. Schaefer, et al, "A Monte Carlo Simulation Approach to Cost Uncertainty Analysis," RAC-TP-349, Research Analysis Corporation, Mar 69.

[40] Frank J. Husic, "Cost Uncertainty Analysis," RAC-P-29, Research Analysis Corporation, May 68.

DOCUMENTATION

Regardless of the ingenuity and inventiveness of the analyst in performing uncertainty analyses, the decision maker cannot profit from them unless the results are properly communicated. It is not possible to promulgate fixed standards of documentation. However, general documentation considerations may be prescribed and these are discussed below.

Addressing the Analyses

The uncertainty analyses must be addressed and the highlights set forth by some combination of text, table, and graph. The analyses should never be assumed capable of speaking for themselves. Pages and pages of computer printouts may contain the essentials of an uncertainty analysis, but are generally ill-suited to set forth the overall results.

Summarizing Results

Most uncertainty analyses should be documented in summary form. This means that the analyst must highlight the major points and omit most of the basic details. It is important to address those aspects that do not have significant impact on costs and benefits as well as those that do.

Showing Complete Results

As indicated earlier in this chapter, a contingency analysis may approximate a separate study. In such cases the results of all contingencies may be documented to approximately the same extent. The second CS_3 economic analysis[41] provides examples of this point. In this study costs of fielding two variations of the CS_3 were presented with and without funding constraints. The constraints in the form of the planned CS_3 annual funding programs in the procurement of equipment and missiles, Army (PEMA) appropriation for FY72-FY75 determined the rate at which CS_3 ADPE could be purchased.

Text vs Appendix

The more detailed aspects of an uncertainty analysis belong in an appendix. CER documentation should usually be presented in an appendix. Reference 14 suggests formats for both complete and skeletal documentation of CERs.

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[41] Office of the Assistant Vice Chief of Staff, Management Information Systems Directorate, "Combat Service Support System Cost Effectiveness Study Update," Sep 71.

6 COMPARING ALTERNATIVES

PURPOSE

Alternatives are compared and ranked in order to facilitate decision making. The relative strengths and weaknesses of competing alternatives can be brought into clearer focus when their costs and benefits are placed together side by side. It should be realized that this process can at best identify a preferred alternative among those considered in the analysis. It cannot guarantee that there is not some better alternative that has not been analyzed.

ANALYSIS FRAMEWORK

There are three general frameworks for comparing and ranking alternatives. These are used for:

- Equal benefit — unequal cost alternatives
- Equal cost — unequal benefit alternatives
- Unequal cost — unequal benefit alternatives.

The analyst should be able to discern which framework is appropriate once he has properly formulated his problem statement. The particular framework often will have an effect on the way system alternative costs and benefits are calculated as well as on the way they are brought together. The framework should not be perceived as something grafted on during the final stages of a study in order to pull together previously determined system alternative costs and benefits for final comparison.

Equal Benefit — Unequal Cost Alternatives

In the case of equal benefits, the preferred alternative is simply the least costly alternative. Equal benefit analyses are appropriate under two circumstances. First, where a given level of effectiveness is

required and the alternatives can be evaluated in terms of the costs of meeting that effectiveness. Second, where the benefits produced by the alternatives can be assumed to be approximately the same. Equality of benefits is all that is required in this case; the common level of benefits need not necessarily be measured.

Figure 10 graphically portrays the analysis appropriate for a fixed-effectiveness problem. The assumed fixed-level requirement is 75 units of effectiveness. Alternatives A and B do not measure up to this requirement and are thus eliminated as feasible alternatives. Alternatives C and D both meet the requirement; however C is the preferred alternative because it is less costly.

Cost reduction proposals, such as those contained in the DepotMAIDS case study in Vol IV, together with purchase/lease and make-or-buy studies are representative of the second type of equal benefit analysis. No reference is made to a measurable level of benefits in such applications. Instead, the analysis is implicitly or explicitly conducted under the assumption that benefits for the alternatives considered are approximately the same.

AR 37-13[7] provides Format A-1 as an optional summary device for documenting the results of cost reduction proposals. The Format (see Fig. 11) presupposes a comparison between two alternatives, one of which is always the status quo. It focuses on the cost savings expected to be realized from implementing the proposed alternative to the status quo. Alternatively, the format is arranged to identify whether the savings expected to be realized by changing from present operations justifies the cost of changing.

Equal Cost — Unequal Benefit Alternatives

It may be possible to construct equal cost alternatives so that the choice among them can be made on the basis of benefits or effectiveness. This is particularly likely to be the case for force structure analyses. For example, it might be possible to equate the cost of a number of field artillery battalions to missile battalions of a given type. If the effectiveness of the "quivalent" number of missile battalions exceeds that for an artillery battalion, the missile battalion would

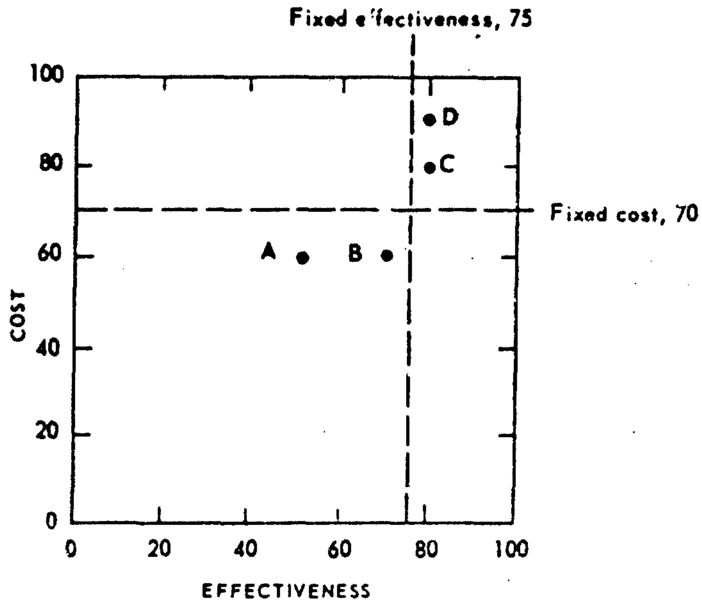

Fig. 10—Graphic Portrayal of Fixed Cost and Effectiveness Levels

Alternative	A	B	C	D
Cost	60	60	80	90
Effectiveness	50	70	80	80

Fixed-Effectiveness Approach:

Assume the required effectiveness is 75. Of the four alternatives C and D meet this requirement. Of these C has the lower cost and is therefore preferred.

Fixed-Cost Approach:

Assume the constrained budget level is 70. Of the four alternatives A and B meet this requirement. Of these B has the higher effectiveness and is therefore preferred.

ECONOMIC ANALYSIS/PROGRAM EVALUATION
SUMMARY OF COSTS FOR
FORMAT A-1

1. Submitting DOD Component: ____________________

2. Date of Submission: ____________________

3. Project Title: ____________________

4. Description of Project Objective: ____________________

5a. Present Alternative: __________ 6a. Economic Life: __________

b. Proposed Alternative: __________ b. Economic Life: __________

7. Project Year	8. Recurring (Operations) Costs a. Present Alternative	8. Recurring (Operations) Costs b. Proposed Alternative	9. Differential Cost	10. Discount Factor	11. Discounted Differential Cost
1.					
2.					
3.					
.					
.					
25.					
12. TOTALS					

Fig. 11 — Sample Format A-1

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A-1

13. Present Value of New Investment:

    a. Land and Buildings ________

    b. Equipment ________

    c. Other (identify nature) ________

    d. Working Capital (Change-plus or minus) ________

14. Total Present Value of New Investment (i.e., Funding Requirements). ________

15. Plus: Value of existing assets to be employed on the project ________

16. Less: Value of existing assets replaced ________

17. Less: Discounted Terminal Value of new investment ________

18. Total New Present Value of Investment $ ________

19. Present Value of Cost Savings from Operations (Col. 11) ________

20. Plus: Present Value of the Cost of Refurbishment or Modifications Eliminated ________

21. Total Present Value of Savings $ ________

22. Savings/Investment Ratio (Line 21 divided by Line 18) ________

23. Rate of Return on Investment ________

Fig. 11 —Sample Format A-1 (Continued)

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A-1

24. Source/Derivation of Cost Estimates: (Use as much space as required)

a. Investment Costs:

(Itemize Project Costs)

1.) Changes in Working Capital

2.) Net Terminal Value

b. Recurring Cost (Operations):

1.) Personnel

2.) Operating

3.) Overhead Costs

c. Other Considerations:

---

25. Name & Title of Principal Action Officer | Date

Fig. 11— Sample Format A-1 (Continued)

be the preferred alternative. If not, the artillery battalion would be the preferred alternative.

A fixed cost level constraint (perhaps budget-induced) may be appropriate for certain types of analysis. Alternatives that do not exceed the cost constraint are feasible alternatives. The preferred alternative is simply that feasible alternative having the greatest effectiveness.

Figure 10 graphically portrays the analysis appropriate for a fixed-cost problem. The assumed constraint is 75 units of cost. Alternatives A and B fall within the constraint and thus are feasible alternatives. Alternatives C and D exceed the constraint and therefore are removed from further consideration. Since Alternative B has greater effectiveness than Alternative A it is the preferred alternative.

Format A of AR 37-13[7] provides a summary device for documenting the costs of an alternative. The format could prove useful for an application similar to that described in the previous paragraph. A separate format (see Fig.12) must be prepared for each alternative considered in a proposal. The format emphasizes total life cycle costs—requiring nonrecurring (R&D and investment) and recurring (operations) costs to be displayed separately and in total for each year in the study time frame.

Formats A and A-1 provide step-by-step procedures for calculating standardized elements of cost. The cost formats can be displayed as summary worksheets (see the DepotMAIDS case study in Vol IV for an example of the utilization of Format A-1). Format B, the counterpart for benefits (and effectiveness) is primarily useful as a checklist rather than as an actual worksheet (see Fig. 13).

Unequal Cost — Unequal Benefit Alternatives

The unequal cost with unequal benefits case is both the most common and the most difficult to arrange for comparison. A basic approach is to order the alternatives from the least to the most costly and show the extent to which extra benefits are associated with each added increment of cost. Normally the existing system or status quo alternative will provide the baseline.

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

1. Submitting DOD Component: ____________________

2. Date of Submission: ____________________

3. Project Title: ____________________

4. Description of Project Objective: ____________________

5. Alternative: ____________ 6. Economic Life: ____________

	8. Program/Project Costs					
7. Project Year	a. Non-Recurring R&D	a. Non-Recurring Investment	b. Recurring Operations	c. Annual Cost	d. Dis-count Factor	e. Discounted Annual Cost
1.						
2.						
3.						
.						
.						
.						
.						
25.						
9. TOTALS						

10a. Total Project Cost (discounted) ________

10b. Uniform Annual Cost (without terminal value) ________

11. Less Terminal Value (discounted) ________

12a. Net Total Project Cost (discounted) ________

12b. Uniform Annual Cost (with terminal value) ________

Fig. 12 — Sample Format A

SUMMARY OF COSTS FOR ECONOMIC ANALYSIS/
PROGRAM EVALUATION STUDIES
FORMAT A

13. Source/Derivation of Cost Estimates: (Use as much space as required)

a. Non-Recurring Costs:

1.) Research & Development:

2.) Investment:

b. Recurring Cost:

c. Net Terminal Value:

d. Other Considerations:

14. Name & Title of Principal Action Officer	Date

Fig. 12—Sample Format A (Continued)

SUMMARY OF OUTPUTS FOR ECONOMIC ANALYSIS
OR PROGRAM EVALUATION STUDIES
FORMAT B

1. Submitting DOD Component: ____________________

2. Date of Submission: ____________________

3. Project Title: ____________________

4. Description of Project Objective: ____________________

5. Alternative: ____________________ 6. Economic Life: ____________

7. Outputs:

   a. Expected Benefits, Output, and Indicators of Effectiveness:

      (Describe and justify)

   b. Non-Quantifiable Benefits: (Describe and justify)

   c. Present Value of Revenues: (Describe and justify)

Fig. 13 — Sample Format B

SUMMARY OF OUTPUTS FOR ECONOMIC ANALYSIS
OR PROGRAM EVALUATION STUDIES
FORMAT B

8. Source/Derivation of Outputs: (use as much space as required)

a. Benefits, Performance and Indicators of Effectiveness:

b. Non-Quantifiable Benefits:

c. Present Value of Revenues:

9. Name & Title of Principal Action Officer | Date

Fig. 13 — Sample Format B (Continued)

In some cases an apparent unequal cost — unequal benefit problem can be translated to one where either costs or benefits are equal. The basis for doing this is the analyst's judgment that the costs or benefits of all system alternatives are in the same ballpark. The purpose of doing this is that equal benefit or equal cost problems are more amenable to analysis and presentation of firm conclusions.

INCORPORATING UNCERTAINTY ANALYSES

Comparisons and rankings must be performed not only for the original data set but for any other data sets employed in uncertainty analyses. Graphical approaches such as those outlined in Chap. V of Ref 1 become particularly useful for portraying the results of such analyses. The reason is that the economic analysis may more closely approximate a continuous problem under uncertainty considerations. For example, if contingency analyses are performed in which fixed benefit or cost constraints are relaxed it becomes possible to graph costs against benefits and to denote the ranges over which the various alternatives are preferred.

Figure 14 depicts the type of diagram that might result from relaxing cost or benefit constraints. Alternative A in the diagram is the preferred alternative over the range R_1 because in this range it achieves a given level of benefits at lower cost than any of the remaining three alternatives. Similarly, Alternatives B and C respectively are the preferred alternatives over ranges R_2 and R_3. Alternative D is always inferior to at least one alternative over all three ranges.

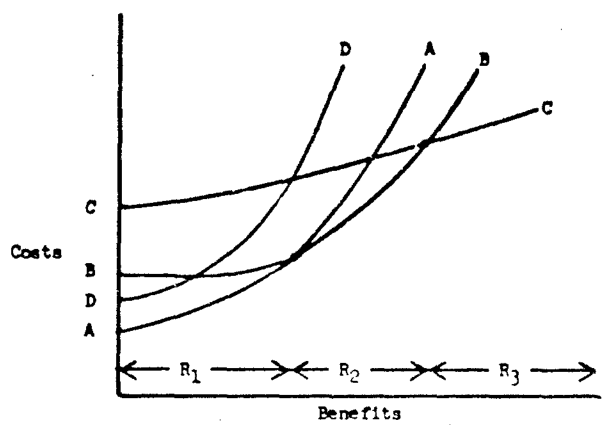

Fig. 14—Graphical Analysis of Preferred Alternatives

FORMULATING RECOMMENDATIONS

By the time the analysis is over, the analyst generally will have formed an opinion concerning the "best" alternative. The question is whether he should formulate a recommendation and insert it in the analysis or whether to refrain from any recommendations and permit the study results to speak for themselves. Some would argue that adoption of the first course would represent an unwarranted invasion into the decision maker's prerogatives. On the other hand, many would point out that by holding back carefully thought out recommendations the analyst is failing to provide the decision maker with an important form of information.

It is difficult to provide specific guidance concerning formulation of recommendations. Sometimes the tasking order or governing directive may provide required guidance. If not, perhaps the best advice is: "Try to discover the decision maker's preference in this area." Certain decision makers will prefer hard and fast recommendations; others will prefer presentation of results without accompanying recommendations.

7 STATISTICAL CONCEPTS

INTRODUCTION

A treatment of economic analyses would not be complete without at least a brief description of some of the statistical concepts which are integral to the design and implementation of complex analyses. This section discusses the design of experiments, functional relationships, probability, sampling, statistical distributions, and statistical inference.

DESIGN OF EXPERIMENTS

The term "design of experiments" refers to how research data are collected and under what conditions the research is to be conducted. After the decision to conduct an economic analysis is made it is often the case that the researcher is so anxious to get started he collects every piece of data in sight before he has given thought as to what he should be collecting and how he should collect it. The purpose of designed experiments is to facilitate proper and adequate collection of information without wasteful expenditure of resources. This objective can be achieved only if the analyst proceeds in a careful and systematic manner from the outset.

Hicks[42] outlines the steps which should be followed in the design of experiments. First, the experiment itself must be clearly defined and then the design must be defined. The definition of the experiment includes a precise statement of the problem to be studied, the choice of dependent variables and independent variables, the range of allowable

[42]Hicks, Charles R., <u>Fundamental Concepts in the Design of Experiments</u>, Holt, Rinehart and Winston, New York, 1964.

values for the independent variables, and the functional relationships between the dependent and independent variables. In many instances it is not possible to clearly define these requirements at the outset. However, by constructing a preliminary set of conditions for the variables and the functional relationships, a logical starting point is defined which facilitates the research and eliminates approaches which are not feasible.

The design of the experiment requires defining the sample sizes to be taken, defining the ordering of the samples, e.g., fixed or random, defining the method which will be used to randomize the sample (if any), and specifying the form of the mathematical model used to describe the experiment. Mathematical procedures are available for determining optimal sample sizes with respect to cost and desired levels of precision.

FUNCTIONAL RELATIONSHIPS[43,44]

A function is a rule that associates with each element in a set X one or more corresponding elements in the set Y. If Y is a function of X, then we say that Y is the dependent variable and X is the independent variable. If only one value of Y is associated with each value of X, then the function is single valued. If two or more values of Y are associated with a single value of X, then the function is multi-valued.

As stated in the previous subsection, one of the tasks of the experimental design approach is to determine the functional relation between the dependent and independent variables. Unless prior knowledge exists with respect to the appropriate form, the researcher must empirically determine a suitable form which conforms to the historical data.

Regression analysis is one of the most frequently used techniques to estimate functional relationships in economic analyses. However, before any regressions should be made the researcher should construct scatter diagrams to determine a visual picture of the relationships. Very often

[43]Hart, William L., College Algebra, D. C. Heath and Company, Boston, 1953.

[44]Purcell, Edwin J., Calculus with Analytic Geometry, Appleton-Century-Crofts, New York, 1965.

a scatter diagram will suggest functional relationships which can then be tested with the more complex tools of regressions analysis. Scatter diagrams are discussed in Appendix C.

Some of the functional forms which are frequently encountered in Army economic analyses are

1. The linear form
2. The logarithmic form
3. The square root form
4. The reciprocal form

These forms are illustrated in Fig. 15.

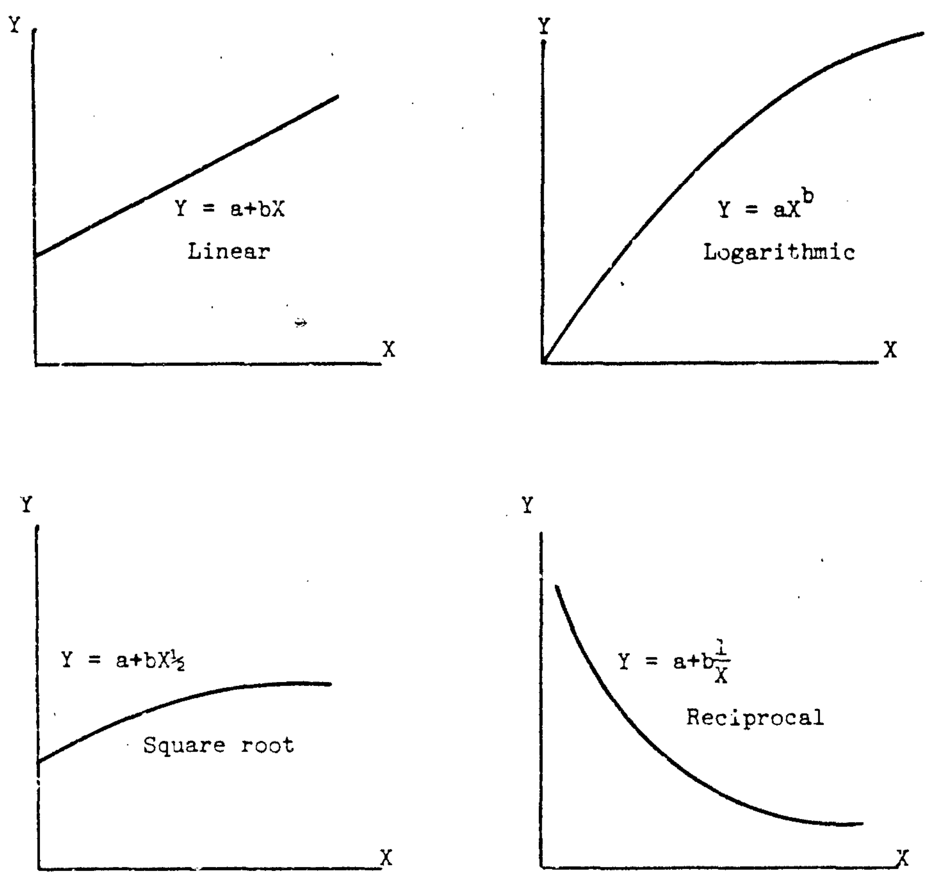

Fig. 15—Simple Functional Relations

PROBABILITY[45,46,47]

The probability of an event is a number in the interval from 0 to 1 which represents the relative likelihood that the event will occur. The term "probability" is familiar to almost anyone who has played poker, bridge, or other chance games. Probability theory is the cornerstone on which statistical methodology is based, and an understanding of probabilities is necessary to effectively apply statistics to problems of economic analysis.

The probability of an event occurring refers to the likelihood of its occurrence. A knowledge of the exact probability of an event does not guarantee that the decision maker can predict the occurrence of that event. The probability of an event refers to the relative frequency of an event in a large number of trials. For example, the probability of obtaining a head on one flip of a coin is 1/2, but it may take as many as 5 or 6 flips of the coin before a head is observed. The meaning is that if one were to flip a coin a large number of times, the percentage of times a head would be observed would approach 1/2 as the number of flips becomes very large.

Mathematically, the definition of probability might be cited as

$$p = \lim_{n \to \infty} \frac{n_A}{n}$$

where p represents the probability of the occurrence of event A

n represents the total number of trials

n_A represents the number of times A occurs in n trials.

Thus, p is read as the probability of an event A and is equal to the ratio of the number of times A occurs in n trials when the number of trials is infinite.

Obviously, to estimate probabilities empirically, one cannot conduct the experiment an infinite number of times. A finite number has to be

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[45] Bryant, Edward C., Statistical Analysis, McGraw-Hill Book Co., New York, 1966.

[46] Drake, Alvin W., Fundamentals of Applied Probability Theory, McGraw-Hill Book Co., New York, 1967.

[47] Hadley, G., Introduction to Probability and Statistical Decision Theory, Holden-Day, San Francisco, 1967.

selected. How large a number does n have to be to provide a reasonable estimate of the true probability? The answer depends on the true probability itself. The rule which applies is that the closer the true probability is to 1/2 the smaller the sample size required to estimate it. For readers who want empirical proof, try flipping a coin 50 times and try casting one die 50 times. Record the frequencies of heads and tails on the coin and the frequencies of the numbers 1 through 6 on the die. Then calculate the relative frequencies of each event, e.g., the number of heads, tails, ones, twos, etc. If the experiment is repeated a number of times, the relative error of estimating the events on the coin where the probability is 1/2 will invariably be less than the relative error of estimating the events on the die where the probability is 1/6 for each event.

The probability that event X will occur is written as

$p(X)$ = probability that event X will occur.

If X is the event that a head appears on one flip of a coin, then

$$p(X) = 1/2.$$

If X is the event that a three appears on one cast of a die, then

$$p(X) = 1/6.$$

It is important to remember that in applying probability theory to problems of economic analysis the actual realization of the outcome is dependent on repeating the experiment enough times to allow the results to converge on the true probabilities. Unfortunately, when dealing with economic problems such as estimating the cost of a new aircraft or designing an attack strategy the number of sample observations is not very large and, consequently, the outcome of the experiment may not conform to the expectations. It is for this reason that extreme care should be taken when interpreting the results of statistical analyses.

SAMPLING[48,49,50]

Statistical sampling is the process of drawing elements from a population in a random manner so that inferences about the population

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[49] Cochran, William G., Sampling Techniques, John Wiley & Sons, Inc., New York, 1963.

may be made on the basis of the sample. In statistics the term population or universe is used to mean the collection of all items or events under consideration for analysis. For example, the population might be all items in a shipment of electronic components, or all employees on a military base. Also, the population may be defined as only a segment of the shipment of electronic components, or a segment of the employees on a military base, e.g., all employees over the age of 40. The point to be made is that the population is defined by its end use. If the objective of the analysis is to determine the characteristics of all employed members of the base over 40, then the population is defined accordingly.

The objective of sampling is to make inferences about the population without having to examine every member of the population. A carefully selected sample enables the researcher to obtain a high degree of precision in estimating the characteristics of the population at a substantially lower cost. Even if cost and time were not a constraint, in many instances it is not possible to sample all members of the population because the members of the population are not readily identifiable or because sampling causes destruction of the items, such as testing wire for tensile strength.

The statistical probabilities or inferences which are made on the basis of the sample are valid only if the sample is randomly selected. "Randomly selected" means that every member of the population has an equal probability of being selected in the sample. Clearly, if some members of the population were significantly more likely to be selected than others, the results would be biased in favor of those with the highest probability of selection.

Techniques are available for increasing the precision of a given sample size and for reducing the cost of a given sample size. Stratification is one method of increasing the precision of a sample of a given

[49] Feller, W., An Introduction to Probability Theory and Its Applications, John Wiley & Sons, New York, 1957.

[50] Mode, Elmer B., Elements of Statistics, Prentice Hall, Inc., Englewood Cliffs, New Jersey, 1961.

size. Stratification involves segmenting the population into subpopulations of members with similar characteristics and then subsampling the members of the subpopulations. The total variability of the sample will be reduced with a corresponding increase in precision.

Cluster sampling is an effective method of reducing the cost of sampling when the population is spread over a large geographical area. This type of sampling is used frequently by the Department of Commerce in the census surveys. Cluster sampling involves segmenting the population into geographic segments, then the geographic segments are randomly selected from which to draw the sample. In some instances clustering may reduce precision and, therefore, should not be used unless the cost of sampling is a major problem.

STATISTICAL DISTRIBUTIONS[50,51]

A statistical distribution may be defined as a listing of all the values a variable may assume and the frequency with which each value occurs in a given number of trials of the experiment.

An example of a frequency distribution for defective pieces of equipment out of 100 shipments of items is given in Table 5.

Table 5

DISTRIBUTION OF NUMBER OF DEFECTIVE PIECES
IN 100 SHIPMENTS OF EQUIPMENT

Number of defective pieces	Shipments with designated number of defects	Fraction
0	50	.50
1	20	.20
2	15	.15
3	8	.08
4	4	.04
5	2	.02
6	1	.01

[51] Duncan, Acheson J., Quality Control and Industrial Statistics, Irwin, Homewood, Illinois, 1965.

The graph of this distribution is given in Fig. 16

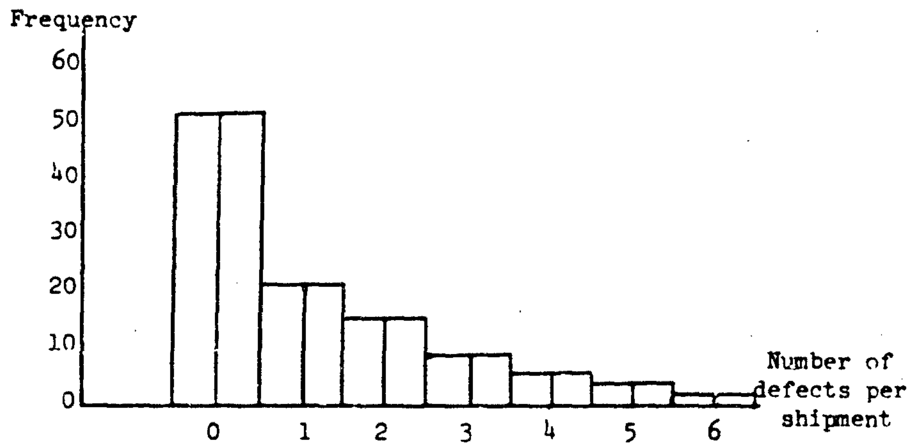

Fig. 16—Frequency Distribution

It can be seen that the graph also may be used to represent the probability of obtaining a specified number of defects. For example, the probability of obtaining a shipment with exactly one defect would be .2.

$$P(1) = .20$$

The probability of obtaining a shipment with less than three defects would be .85.

$$P(0) + P(1) + P(2) = .50 + .20 + .15$$
$$= .85$$

The probability of obtaining a shipment with at least three defects would be .15.

$$P(3) + P(4) + P(5) + P(6) = .08 + .04 + .02 + .01$$
$$= .15$$

STATISTICAL INFERENCE [41,46,49]

Statistical inference may be defined as the process of drawing conclusions about a population from a sample taken from that population. The population is typically characterized by two parameters, the mean and the variance. The mean is a measure of central tendency which gives the average value for all members in the population and the variance is a measure of the dispersion of the values around the average. The square root of the variance is called the standard deviation. The sample also is characterized by a mean and a variance. The mean and the variance of the sample are used to make inferences about the mean and the variance of the true population.

The mean of the population is usually symbolized by μ and the variance is symbolized by σ^2. The formulae for these parameters are

$$\mu = \frac{\sum_{i=1}^{N} X_i}{N}$$

where X_i is the value of the ith element in the population

N is the number of individuals in the population

$$\sigma^2 = \frac{\sum_{i=1}^{N} (X_i - \mu)^2}{N}$$

A knowledge of the true mean and variance of the population is sufficient to calculate the probability of selecting any element from the population with a random sample. In most applications to economic analyses the true mean and variance are not known and have to be estimated from the sample itself.

It can be shown mathematically that the sample mean is an unbiased estimate of the population mean. This means that the average value of all possible samples of each size will equal the true population mean. The sample mean is represented by $\overline{X}$ and its formula is

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

where n is the number of elements included in the sample.

The sample variance is represented by S^2 and its formula is

$$S^2 = \frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n - 1}$$

The sample variance is also an unbiased statistic.

The use of the sample mean and variance in statistical testing of hypotheses will be illustrated in Appendix C in the section on <u>Significance Testing</u>.

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8 APPENDIXES

INTRODUCTION

The appendices contain descriptions of some of the important techniques used to perform economic analyses. The format used to present the techniques is as follows: Purpose, General Description, Sample Application, Limitations, and References.

Maximum use has been made of existing DOD and Service publications in preparing the appendices. Where possible, material from such sources has been simply reproduced. Commercial publications have been used for additional background.

Since one of the purposes of the appendices is to alert the reader to additional sources, attempts have been made to assure that the publications cited are widely available. Generally, at least two sources are indicated in each description of a concept or technique and are annotated where helpful.

Appendix A

ACCOUNTING AND FINANCIAL MANAGEMENT TECHNIQUES

A.1 BREAK-EVEN ANALYSIS

PURPOSE

Break-even analysis is used in commercial applications to help investigate the relations among sales, costs, plant size, and other factors related to profits. The sales break-even point is defined as the sales volume necessary for an enterprise to exactly match revenues and expenses. The nature of expenses in relation to sales is graphed, the break-even point determined, and the graph used at other sales volumes to estimate profits or losses.

In the military context the focus is generally not on determining the sales volume necessary to break even. Instead, the purpose of the analysis is to determine break-even points such as the production quantity that equals the present value of a required investment or whether to follow a make-or-buy policy in a given situation.

GENERAL DESCRIPTION

A break-even point separates a production range into two sectors—economic and noneconomic. Depending on the type of analysis, this point can be defined as the production quantity with a savings/investment (S/I) ratio of 1.0, a purchase/production cost ratio of 1.0, etc.

A break-even analysis typically assumes linear returns. Where the return function is linear throughout all production quantities, no more than two quantities with related cost and "revenue" data are needed for graphing purposes. Figure 17 shows a return function representing the percent return of savings (or foregone purchases) on investment (or production costs). The data used in its construction are as follows:

Quantity/Day	Investment ($)	Annual Savings ($)	S/I
100	1000	200	.2
200	1000	400	.4

It should be noted that for the return line in Fig. 17 only data on one of the above production quantities would actually be required. This results from the fact that the line passes through the origin.

The break-even production quantity occurs at the juncture of the return line and a horizontal line drawn at the return ratio of 1.0—a production quantity of 500 in Fig. 17. It can be seen that all production quantities to the left of 500 have a return ratio less than 1.0 and all to the right a ratio greater than 1.0.

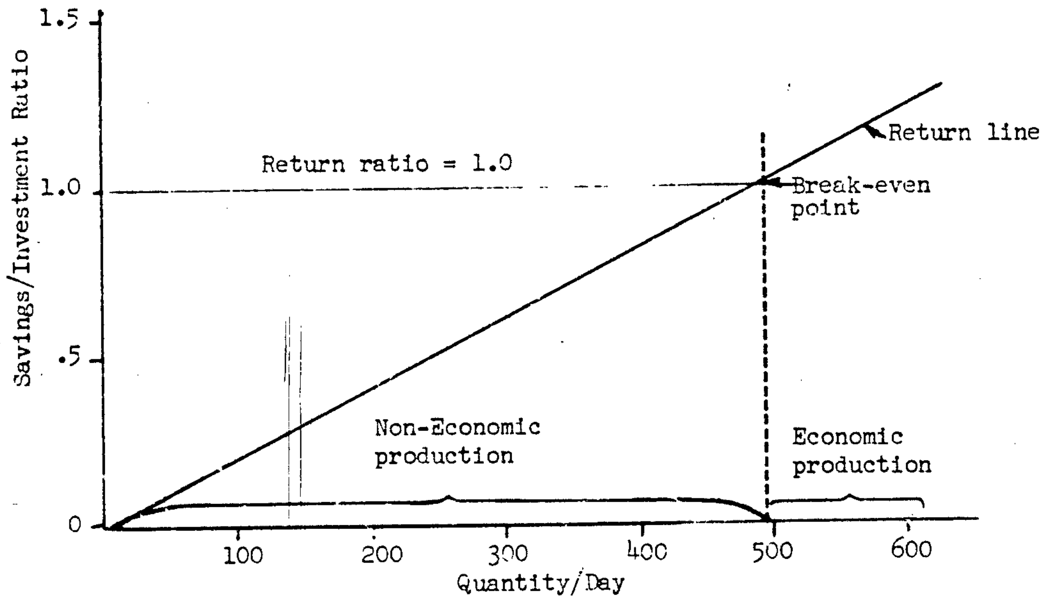

Fig. 17—Sample Break-Even Chart

SAMPLE APPLICATION

The following example is taken from the Munitions Command (MUCOM) Economic Analysis Manual[1] (pp VII-13 to VII-23).

The manual notes that the type of information provided by break-even analysis is twofold:

First, we know what quantity of production is required before the project becomes worthwhile, economically speaking. Second, we can estimate the economic potential of proposed investments at all ranges of production, including, for example, the mobilization level, current production level, or any production level.

The manual provides two formulas for mathematically determining the break-even point. The first formula is applicable to projects that do not involve an increase in production quantity (Fig. 17, for example). The second formula is used in situations where the proposed project will increase production quantity.

$$X = \frac{Y}{KS_1} \tag{1}$$

$$X = \frac{(KS_2CC - KS_1CC) + Y}{KS_2} \tag{2}$$

where:

X = break-even quantity expressed in tons per day

K = constant which depends upon economic life (10 years = 6.447)

S_1 = savings/ton/year for quantities less than current capacity

S_2 = savings/ton/year for quantities greater than current capacity

CC = current capacity, expressed in tons per day

Y = present value of investment

A sample problem involving increased plant capacity is described below.[1]

Let's assume that Plant A is considering replacing its TNT lines with new lines. Besides increasing operating efficiency, it will also increase capacity from 400 to 700 tons per day. Mobilization requirements are 685 tons per day, but current requirements are 425 tons per day. The present value of the investment is $15,000,000. Differential costs per ton are as follows:

	Present Facility	Proposed Facility
First 400 tons:		
Personnel	$3.06	$ .92
Maintenance	2.72	1.39
Utilities	4.91	2.20
Overhead & Fringe	1.05	.32
Manuf. Overhead	2.29	.37
Total	$14.03	$5.20
401 to 685 tons.	$90.00	$36.76

The cited differential costs per ton form most of the basic information required to calculate the expanded facility break-even point (see Eq 2 for the appropriate calculation). Factors, their values, and sources are as follows:

Factor	Value	Source
K	6.447	Value appropriate for uniform savings over 10-year period at 10 percent discount rate—Table B AR 37-13.[2]
CC	400	Plant A current capacity in tons per day—part of problem specification.
S_2	(\$90.00 - \$36.76) x 360	(Difference in savings between present and proposed facility per ton for daily tonnage exceeding 400 tons) x number of production days per year
S_1	(\$14.03 - \$5.20) x 360	(Difference in savings between present and proposed facility per ton for daily tonnage less than 400 tons) x number of production days per year
Y	$15,000,000	Present value of investment required to increase Plant A production capacity from 400 to 700 tons per day—part of problem specification.

The graphical solution to the break-even analysis for the hypothetical plant expansion problem is shown at Fig. 18. The return line was computed by calculating S/I ratios at three production levels—one less than current capacity, current capacity, and one greater than current capacity. The plotting data are as follows:

	Production Levels- Tons per Day		
	200	400	685
Annual Savings	$ 635,760	$1,271,520	$ 6,733,944
Savings—10 years (discounted)	4,098,745	8,197,489	43,413,736
Savings/investment ratio	.27	.55	2.9

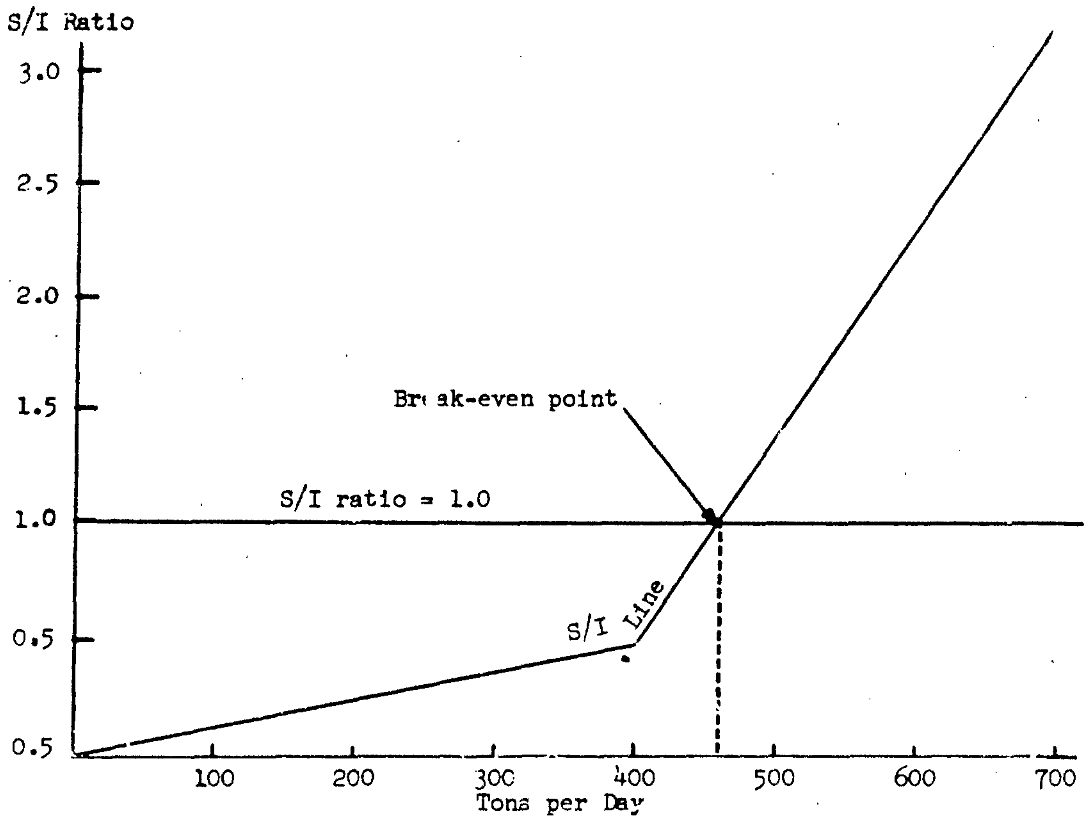

Fig. 18—Break-Even Analysis

LIMITATIONS

The linear return assumption underlying break-even analysis makes it simple to use but inappropriate for many real problems. Break-even analysis is most effective when applied to short range problems involving relatively limited policy alternatives. The technique should be used with caution in any economic analysis study that involves extrapolation over a considerable time period and/or range of production.

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A.2 DISCOUNTING

PURPOSE

Discounting is one of two techniques used to adjust dollar amounts occurring in different years to a common base. Discounting adjusts for the time value of money through consideration of an appropriate interest rate. Price indexes adjust for changes in the purchasing power of the dollar over time, i.e., inflation or deflation.

Discounting permits comparisons of alternative time-phased cash flows by translating the flows into present day dollar totals. Such a dollar total is commonly referred to as the present value of the cash flow. A 10 percent interest rate is required to be used in computing the present values of costs and benefits for most Army economic analyses.[1]

DESCRIPTION

The theory underlying the use of discounting is that the productive uses of money make a dollar today more valuable than a dollar in the future. One productive use is to loan money and to accrue interest over the life of the loan.

At an interest rate of "i" compounded annually a loan of P would grow to a sum of F_1 at the end of one year as follows:

$$F_1 = P + (Pxi) \text{ or factoring,}$$

$$F_1 = P \times (1+i).$$

The sum P represents the return of the original principle and P x i represents the interest earned.

The future value of \$1 for 1 year at 10 percent interest is then

$$F_1 = \$1\ (1+.1)$$

$$F_1 = \$1\ (1.1)$$

$$F_1 = \$1.10$$

Placing a loan for 2 years is equivalent to placing a loan for one year and reinvesting the proceeds, provided that reinvestment can be made at the same rate of interest. Thus,

$$F_2 = F_1\ (1+i) = P(1+i)(1+i)$$

$$F_2 = P\ (1+i)^2$$

$$F_2 = \$1\ (1.1)^2 = \$1.21$$

where F_2 is the future value of the amount F_1 after 1 year or the future value of P after 2 years. In general, F_n, the future value of P at the end of n years, can be shown to be

$$F_n = P(1+i)^n.$$

For example, at a 10 percent interest rate the future value of \$1 at the end of 5 years is

$$F_5 = \$1(1.1)^5 = \$1(1.61) = \$1.61$$

To evaluate a future dollar in terms of its present value, the above logic must be reversed. That is, if F_n is the amount of money spent or received at the end of the year n, then its present value P with respect to interest rate i is simply

$$P = \frac{F_n}{(1+i)^n} \quad .$$

The present value of a future amount n years from now is equal to the future amount, F_n, times the discount factor, $1/(1+i)^n$. For example, the present value of \$1.61 5 years from now is \$1 at a 10 percent interest rate.

The above calculations assume that cash flows occur at the end of each year. Since cash flows may also occur throughout the year, the end-of-year discount factor, $1/(1+i)^n$, is often replaced by the continuous

discount factor,

$$\frac{i}{(1+i)^n \ln (1+i)} \quad \text{for } n \geq 1 .$$

The continuous discount factor is equivalent to the arithmetic average of beginning and end of the year discount factors found in standard end-of-year present value tables. Table 6 contains the continuous discount factors at 10 percent interest for 25 years. Table 7 is the cumulative total of the discount factor appearing in Format A. These tables were extracted from AR 37-13 and provide the discount factors for use in Army economic analyses.

APPLICATION

The following example is taken from the Munitions Command (MUCOM) Economic Analysis Manual[2] (Section II). The purpose is to demonstrate the technique of discounting, and while the example is involved only with costs, it should be remembered that both receipts and expenditures can be discounted in an economic analyses. The project cost format used in this example is standard for Army investments.

> The Golden Star Corporation at Lost Creek, Tinbucktwo, must do something about the excess oil that it has been dumping into Sunflower Lake. Pollution control authorities have given Golden Star two years to improve its pollution of Sunflower Lake to an acceptable level.
>
> You have explored all alternatives and found two avenues open. They are:
>
> 1. Buy a filtration unit from Poor Boy Company at a cost of $80,000. Since Poor Boy is short on funds, a downpayment of $60,000 would be required when the order is placed. The balance would be paid when the unit is installed, approximately 23 months later. The unit is guaranteed to maintain acceptable emission levels for 10 years. Labor costs to run the unit are $2,000 per year.
>
> 2. The Union Machine Company has a patent on a new process which will also maintain acceptable emission levels. This process can be installed at the beginning of Year 3 and will be operational for the entire year. The process which will last five years can be installed in 10 minutes and costs $10,000

TABLE 6 1/

PRESENT VALUE OF $1 (Single amount - To be used when cash-flows accrue in different amounts each year).

TABLE 7 2/

PRESENT VALUE OF $1 (Cumulative Uniform Series - To be used when cash-flows accrue in the same amount each year).

Project Year	Table 6: 10%	Table 7: 10%
1	0.954	0.954
2	0.867	1.821
3	0.788	2.609
4	0.717	3.326
5	0.652	3.977
6	0.592	4.570
7	0.538	5.108
8	0.489	5.597
9	0.445	6.042
10	0.405	6.447
11	0.368	6.815
12	0.334	7.149
13	0.304	7.453
14	0.276	7.729
15	0.251	7.980
16	0.228	8.209
17	0.208	8.416
18	0.189	8.605
19	0.172	8.777
20	0.156	8.933
21	0.142	9.074
22	0.129	9.203
23	0.117	9.320
24	0.107	9.427
25	0.097	9.524

1/ Factors are based on continuous compounding of interest at the stated effective rate per annum, assuming uniform cash flows throughout stated one-year periods. These factors are equivalent to an arithmetic average of beginning and end of the year compound amount factors found in standard present value tables.

2/ Table B factors represent the cumulative sum of the factors in Table A at the end of any given year.

installed. Union agreed to sell Golden Star a replacement unit at the end of five years for $10,000. Union will charge $1,000 for removal of old unit plus the used materiel and parts which are valued at $2,000. Labor costs using Union's process are $10,000 per year.

Table 8 compares the actual cash flows and the discounted cash flows for the Poor Boy and Union Machine alternatives. It can be seen that the total costs of the two systems are $100,000 and $121,000, respectively, but the total discounted cost or present value costs are $85,236 and $66,539, respectively. The least costly alternative, the Union Machine unit, is today more than $18,000 less costly than the Poor Boy unit even though for the twelve-year period the cash flow to Union Machine Company will be $20,000 more than to Poor Boy Company.

It should be noted that a third alternative, ceasing operations, is available. In this case a more thorough economic analysis would be required which considers all costs associated with the Golden Star operation as well as anticipated revenues from continued operation. Only in this way could the Golden Star operations be analyzed in terms of its profitability.

LIMITATIONS

Discounting is an established method of adjusting cash flows to take into account the opportunity costs of capital. It "is not a cost estimating technique in the sense that it makes the figures more valid or accurate."[3] Benefit or cost figures that are unreliable before discounting will remain unreliable after discounting.

The 10 percent interest rate established as the standard for discounting in Army economic analyses is intended to represent the returns that are foregone by investing in a public rather than private project.[1] The rate is not intended to incorporate considerations of uncertainty or of inflation.

TABLE 8

ECONOMIC ANALYSIS—DOD INVESTMENTS
SUMMARY OF PROJECT COSTS
FORMAT A

1. Submitting DoD Component: Golden Star Corporation
2. Date of Submission: April 71
3. Project Title: Sunflower Lake Pollution
4. Description of Project Objective: Clear up Pollution Sunflower Lake
5. Alternative: Poor Boy Unit 6. Economic Life: 10 years

7. Project Year	8. Project Costs a. Nonrecurring Investment	b. Recurring Operations	c. Annual Costs	d. Discount Factor	e. Discounted Annual Cost
1	$60,000	0	$60,000	.954	$57,240
2	20,000	0	20,000	.867	17,340
3		$2,000	2,000	.788	1,576
4		2,000	2,000	.717	1,434
5		2,000	2,000	.652	1,304
6		2,000	2,000	.592	1,184
7		2,000	2,000	.538	1,076
8		2,000	2,000	.489	978
9		2,000	2,000	.445	890
10		2,000	2,000	.405	810
11		2,000	2,000	.368	736
12		2,000	2,000	.334	668
9. TOTALS	$80,000	$20,000	$100,000	7.149	$85,236

10a. Total Project Cost (discounted) $85,236

ECONOMIC ANALYSIS—DOD INVESTMENTS
SUMMARY OF PROJECT COSTS
FORMAT

1. Submitting DoD Component: Golden Star Corporation
2. Date of Submission: April 71
3. Project Title: Sunflower Lake Pollution
4. Description of Project Objective: Clear up Pollution Sunflower Lake
5. Alternative: Union Machine 6. Economic Life: 5 years

7. Project Year	8. Project Costs a. Nonrecurring Investment	b. Recurring Operations	c. Annual Costs	d. Discount Factor	e. Discounted Annual Cost
1	-0-	-0-	-0-	.954	-0-
2	-0-	-0-	-0-	.867	-0-
3	$10,000	$10,000	$20,000	.788	$15,760
4		10,000	10,000	.717	7,170
5		10,000	10,000	.652	6,520
6		10,000	10,000	.592	5,920
7		10,000	10,000	.538	5,380
8	11,000	10,000	21,000	.489	10,269
9		10,000	10,000	.445	4,450
10		10,000	10,000	.405	4,050
11		10,000	10,000	.368	3,680
12		10,000	10,000	.334	3,340
9. TOTALS	$21,000	$100,000	$121,000	7.149	$66,539

10a. Total Project Cost (discounted) $66,539

CITED REFERENCES

1. Dept of Army, "Economic Analysis and Program Evaluation of Resource Management," AR 37-13, Apr 73.

2. Munitions Command, Office of the Comptroller, Cost Analysis Division, "Economic Analysis Manual," Mar 72.

3. Dept of Defense, "Economic Analysis Handbook," 2d ed, undated.

A.3 UNIFORM ANNUAL COSTING METHOD

PURPOSE

Uniform annual costing method is an extension of the discounting technique which should be used when alternatives have different project lives. It is obtained by dividing the total present value cost by the sum of the discount factors for the years in which an alternative yields benefits. The alternative with the smallest uniform annual cost is assumed to be the least costly. It is not appropriate to compare the present value costs of alternatives with different project lives. The appropriate method is to compare the uniform annual costs.

DESCRIPTION

Using simple cash flow diagrams, the relationships among actual cost flow, present value cost, and uniform annual cost can be established. A typical expenditure cash flow for an investment might look like Fig. 19. Investment expenditures are made at the beginning of a project while in the latter years (2 through n) recurring costs are required to maintain the project while benefits from the project are realized.

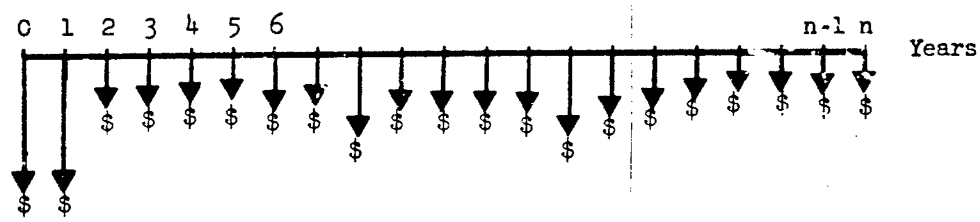

Fig. 19—Actual Cost Flow

The technique of discounting allows the cash flows represented in Fig. 19 to be represented by one amount in today's money. This amount, the present value cost, takes into consideration the time value of money and is presented by Fig. 20.

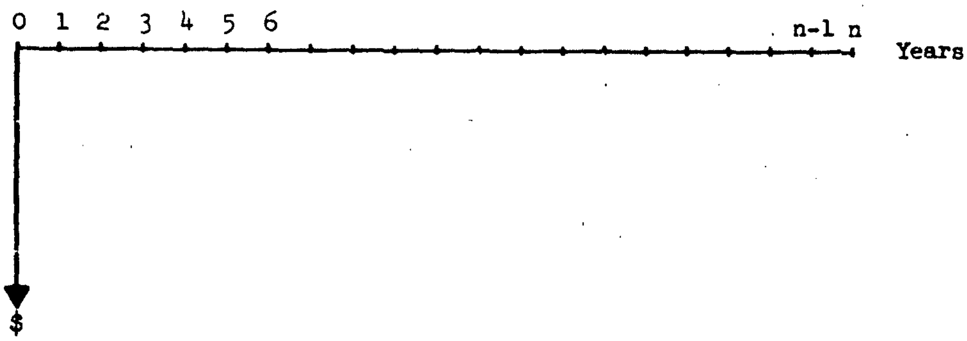

Fig. 20—Present Value Cost

It is important to note that the cash flows illustrated in Figs. 19 and 20 are equivalent, and there would be complete indifference between the two cash flows.

The uniform annual cost is calculated by dividing the present value cost by the sum of the discount factors for the years over which the project yields benefits. The sum of the discount factors is from year 2 through year n for this example because benefits are not realized until year 2. Figure 21 represents the uniform annual cost flow. This is the constant dollar amount that paid annually throughout the beneficial life of the project would just equal in discounted sum the present value cost for the project.

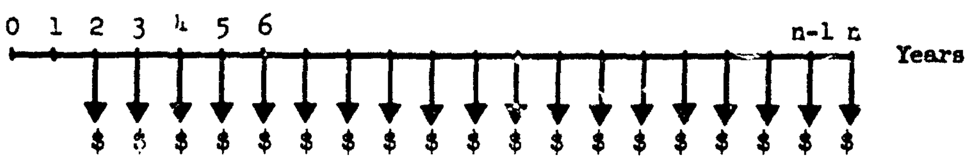

Fig. 21—Uniform Annual Cost

To summarize, the cash flows represented by Figs. 20, 21, and 22 are equivalent and there would be complete indifference in choosing among the three.

APPLICATION

The following example has been based on the Munitions Command (MUCOM) Economic Analysis Manual[1] Section II. It is intended to demonstrate the proper use of uniform annual costs for alternatives with different project lives and represents a continuation of the example contained in the Discounting section of this appendix. The format used to display project costs is the standard format for all DOD investments.

Problem

The Golden Star Corporation has been notified by the Union Machine Company that Union Machine will no longer agree to sell Golden Star a replacement unit at the end of 5 years for $10,000. Moreover, the installed cost of the process at the beginning of Year 3 has risen to $20,000. Union Machine will guarantee the entire process for 8 years of operation instead of the original 5 years.

Analysis

Union Machine's decisions do not affect the economic analysis of the Poor Boy alternative but they do necessitate the calculation of uniform annual costs for both alternatives (the project lives are no longer equal). Table 9 shows the Poor Boy alternative cash flow and the present value cost as before. The uniform annual cost also has been calculated by dividing the present value cost, $85,236 by 5.328, the sum of the discount factors for those years in which the Poor Boy unit would operate (years 3 through 12). The uniform annual cost of $15,998 means that Golden Star Corporation would be indifferent to paying a lump sum of $85,236 today for the Poor Boy unit for years 3 through 12 or paying $15,998 per year for years 3 through 12 for the same unit.

Table 10 shows the revised cash flow and present value cost for the Union Machine alternative. The uniform annual cost of $13,407 was calculated by dividing $62,020 by 4.626, the sum of the discount factors (Col d.) for years 2 through 10. A comparison of uniform annual costs

Table 9

ECONOMIC ANALYSIS—DOD INVESTMENTS
SUMMARY OF PROJECT COSTS
FORMAT A

1. **Submitting DoD Component:** Golden Star Corporation
2. **Date of Submission:** April 71
3. **Project Title:** Sunflower Lake Pollution
4. **Description of Project Objective:** Clear up Pollution Sunflower Lake
5. **Alternative:** Poor Boy Unit 6. **Economic Life:** 10 years

7. Project Year	8. Project Costs a. Nonrecurring Investment	b. Recurring Operations	c. Annual Costs	d. Discount Factor	e. Discounted Annual Cost
1	$60,000	0	$60,000	.954	$57,240
2	20,000	0	20,000	.867	17,340
3		$2,000	2,000	.788	1,576
4		2,000	2,000	.717	1,434
5		2,000	2,000	.652	1,304
6		2,000	2,000	.592	1,184
7		2,000	2,000	.538	1,076
8		2,000	2,000	.489	978
9		2,000	2,000	.445	890
10		2,000	2,000	.405	810
11		2,000	2,000	.368	736
12		2,000	2,000	.334	668
9. TOTALS	$80,000	$20,000	$100,000	7.149	$85,236

10a. **Total Project Cost (discounted)**	$85,236	
10b. **Uniform Annual Cost (without terminal value)**		$15,998
11. **Less Terminal Value (discounted)**	-0-	
12a. **Net Total Project Cost (discounted)**	$85,236	
12b. **Uniform Annual Cost (with terminal value)**		$15,998

13. **Source/Derivation of Cost Estimates: (use as much space as required)**
   a. **Nonrecurring Costs:**
      1) **Research & Development:**
      2) **Investment:** $80,000
   b. **Recurring Cost:** $20,000
   c. **Net Terminal Value:** -0-
   d. **Other Considerations:**

14. Name and Title of Principal Action Officer	Date

Table 10

ECONOMIC ANALYSIS—DOD INVESTMENTS
SUMMARY OF PROJECT COSTS
FORMAT A

1. **Submitting DoD Component:** Golden Star Corporation
2. **Date of Submission:** April 71
3. **Project Title:** Sunflower Lake Pollution
4. **Description of Project Objective:** Clear up Pollution Sunflower Lake
5. **Alternative:** Union Machine 6. **Economic Life:** 8 years

7. Project Year	8. Project Costs a. Nonrecurring Investment	b. Recurring Operations	c. Annual Costs	d. Discount Factor	e. Discounted Annual Cost
1	-0-	-0-	-0-	.954	-0-
2	-0-	-0-	-0-	.867	-0-
3	$20,000	$10,000	$30,000	.788	$23,640
4	-0-	10,000	10,000	.717	7,170
5	-0-	10,000	10,000	.652	6,520
6	-0-	10,000	10,000	.592	5,920
7	-0-	10,000	10,000	.538	5,380
8	$20,000	10,000	10,000	.489	4,890
9		10,000	10,000	.445	4,450
10		10,000	10,000	.405	4.050
11					
12					
9. TOTALS	$20,000	$80,000	$100,000	6.447	$62,020

10a. Total Project Cost (discounted)	$62,020	
10b. Uniform Annual Cost (without terminal value)		$13,407
11. Less Terminal Value (discounted)	-0-	
12a. Net Total Project Cost (discounted)	$62,020	
12b. Uniform Annual Cost (with terminal value)		$13,407

13. Source Derivation of Cost Estimates: (use as much space as required)

- **a. Nonrecurring Costs:**
  - **1) Research & Development:**
  - **2) Investment:** $20,000
- **b. Recurring Cost:** $80,000
- **c. Net Terminal Value:** -0-
- **d. Other Considerations:**

14. Name and Title of Principal Action Officer	Date

shows that the Union Machine alternative remains the least-cost alternative although it must be remembered that Union Machine will operate for eight years, opposed to the ten years for the Poor Boy unit. Without additional facts, it is impossible to evaluate this intangible although it is possible for either the shorter or longer project to be more advantageous to Golden Star.

LIMITATIONS

Uniform annual cost calculations are an extension of discounting and thus share its limitations (see Discounting in this Appendix). Moreover the uniform annual cost approach is approved by economic analysis guidance[2] only when the economic lives cannot somehow be set equal:

> The economic lives for the alternatives should be set, whenever possible, so that the alternatives yield benefits for the same period of time.
>
> If this is not possible, use the uniform annual cost computation ... to provide a more complete analysis of alternatives with unequal lives.

CITED REFERENCES

1. Munitions Command, Office of the Comptroller, Cost Analysis Division, "Economic Analysis Manual," March 1972.

2. Dept of Army, "Economic Analysis and Program Evaluation of Resource Management," AR 37-13, April 1973.

Appendix B
ECONOMICS AND MILITARY COSTING

B.1 LEARNING CURVE

PURPOSE

Learning curves are utilized for data adjustment and for cost estimating purposes. Ideally, the learning curve captures and isolates the effect of cumulative production on the recurring cost of item production. Contract personnel find learning curves based on individual producers useful in negotiations of follow-on contracts. A cost or economic analyst, however, is more likely to use the curve across producers and often in conjunction with a cost estimating relationship (CER).

A learning curve can be used to normalize cost of items by adjustment of all items to a common production level. With the disturbing influence of production quantity removed, a CER can be developed on the basis of the adjusted costs and item physical and performance data. The values of the CER coefficients would be sensitive to the selected common production level. A learning curve can be used in conjunction with a CER based on a given production quantity to estimate costs at other quantities.

DESCRIPTION

The learning curve is an important element in the costing of complex military hardware, particularly to aircraft and missiles. The basic concept underlying the learning curve is that each doubling of cumulative production is accompanied by a constant percentage decline in cost. Cost under one formulation represents the cost of a particular unit (e.g., unit 100) and under a second represents the average cumulative cost (e.g., units 1 to 100). For either formulation the expression of the curve is as follows:

$$y = ax^b$$

where y = unit cost
x = cumulative production
a = first unit cost
b = constant equal to or less than 0.

Mathematically, the learning curve is a special type of power function—one with a nonpositive exponent. Like all power functions, learning curves will graph as straight lines on log-log graph paper. Figure 22 reproduces a hypothetical learning curve with a slope of .8. For this curve the cost at quantity 2X is equal to .8 times the cost at quantity X, where cost can be either unit or cumulative average. More generally, for a learning curve with an (S x 100)% slope the cost at quantity 2X is equal to S times the cost at quantity X.

Special computer programs exist for developing learning curves. Often, however, they can be suitably fitted through standard regression techniques or even by visual inspection. For some purposes learning curves (or at least learning curve slopes) are utilized at assumed values rather than ones developed directly from empirical data.

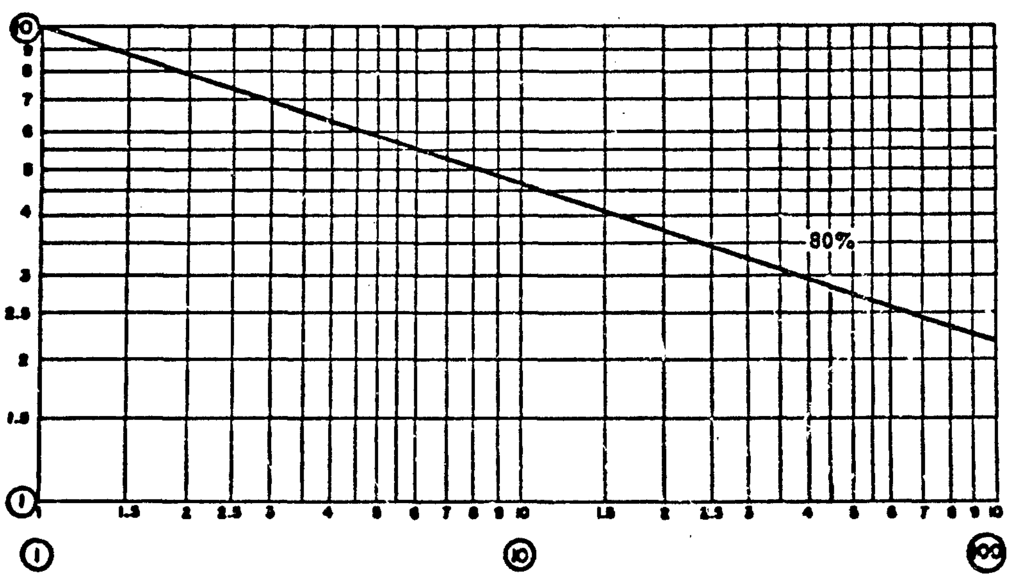

Fig. 22—Learning Curve--80 Percent on Logarithmic Scales

APPLICATION

The Missile Command (MICOM) SCAMP study illustrates how assumed learning curve slopes can be used to adjust data prior to development of CERs.[1] The objective of the study was to develop CERs for estimating the cumulative average cost and cumulative average manhours for producing missile motors. The various motors had been produced in significantly different quantities. To standardize the motors to a common quantity, an assumed slope of 95 percent was used with cost and a slope of 90 percent with manhours. Actual costs or manhours for the motors were adjusted to conform with a production quantity of 1000. Technical characteristics (motor weight, total impulse, etc.) were then examined for relationship to costs or manhours and regressions developed accordingly.

The Electronics Command (ECOM) CER Manual illustrates combined use of CER and learning curve, where both relationships have an empirical origin.[2] Cost and quantity data were secured for nine frequency modulated (FM) transceivers. After suitable adjustment of cost data by price indexes to remove price level changes, a unit learning curve was developed for each transceiver. The average slope (87%) of the nine curves was computed and used to normalize the nine transceivers to a production quantity of 10,000. Various CERs were then developed, with the preferred one relating unit acquisition cost at quantity 10,000 to power output (watts) and number of channels.

The cost of any future FM transceiver, exclusive of price level changes, could then be estimated from the derived regression and average learning curve slope, provided that data could be secured on the transceiver power output and number of channels. The regression would permit estimation of transceiver cost at unit 10,000 ($C_{10,000}$). The learning curve exponent always bears a one-to-one correspondence to slope (see Asher pp 16-17[3] and Batchelder pp 96-97[4]), the exponent appropriate to an 87 percent curve being -.200913. Thus, to secure the learning curve appropriate to a particular transceiver all that is required is to solve for first unit cost (a) in the following equation:

$$C_{10,000} = a \times (10,000)^{-.200913}$$

LIMITATIONS

The problems of estimating learning curves are similar to the problems of estimating CERs. Generally the data are originated by others for somewhat different purposes than estimating relationship development, the items in the sample may be heterogeneous, and the future items whose cost is to be predicted may differ significantly from those in the sample.

The application of learning curves is relevant to only the recurring portion of production costs. It measures true learning only when all one time (or start-up) costs have been removed from total production costs and the remaining costs converted to constant dollars. Failure to remove nonrecurring costs and failure to convert to constant dollars (assuming continuing inflation) have reinforcing effects on the learning curve slope; both tend to bias the slope upward, i.e., understate learning. There are factors that can lead to overstatement of learning. Learning would be overstated, for example, if the procurement history of a multi-Service item were ignored in favor of that portion going only to Army customers.

The COA Costing Methodology Handbook provides the following guidance on learning curves:[5]

> The learning curve is constructed and used under the assumption that there are no significant effects on labor productivity from alterations in the conditions of production in the form of the following—(a) Alterations in the rate of production; (b) Engineering modifications; and, (c) Changes in the level of technology. The only significant factor affecting labor productivity has to do with production experience accumulated (and the increased efficiency this implies). It is this set of circumstances which underlies the use of any learning curve. It must be recognized, therefore, that when the conditions of production change, the applicability of the learning curve may be called into question.

CITED REFERENCES

1. US Army Missile Command, "SCAMP: Systems Characteristics Affecting Missile Production," 25 November 1963.

2. US Army Electronics Command, "The Formulation of Cost Estimating Relationships: An Engineering Approach," June 1970, pp 57-78.

3. Harold Asher, "Cost-Quantity Relationships in the Airframe Industry," R-291, The RAND Corporation, 1 July 1956.

4. C. A. Batchelder et al, "An Introduction to Equipmemt Cost Estimating," RM-6103-SA, The RAND Corporation, December 1970, Section V.

5. Dept of Army, Comptroller of the Army, "Costing Methodology Handbook," April 1971, pp 4-22 to 4-29.

OTHER REFERENCE

1. Alfred D. Stament and Carl Wilbourn, "Cost Estimating Relationships: A Manual for the Army Materiel Command," RAC-TP-449, Research Analysis Corporation, May 1972, pp II-2-31 to II-2-41.

B.2 PRICE INDEXES

PURPOSE

The purpose of a price index is to increase the comparability of dollar totals reported over time (or place) by adjusting all costs to a common year basis. The economic analyst will be faced with the need for adjustment when attempting to derive cost estimating relationships (CERs) and learning curves; or when simply attempting to appropriately update past costs and cost factors for direct use. The goal of the analyst is to place all costs in terms of constant dollars, i.e., dollars at the value of the base year.

An inflation index is designed to change dollars from constant values to that of the year or years of interest. AR 37-13 recognizes that consideration of possible continuation of inflation into the future can change the relative attractiveness of alternatives.[1] The regulation therefore encourages the incorporation of inflation considerations into economic analyses. The basic analysis must first be completed in terms of constant dollars.

DESCRIPTION

A price index is a summary indicator of the level of prices for selected items, commodities, or activities at one time or geographic area compared to another. The time period or place selected as base is assigned an index of 100. Indexes for other periods or places are interpreted against the standard of 100 in simple percentage terms, i.e., indexes of 110 and 90 respectively represent a 10 percent increase and decrease over the base.

Index numbers can be constructed by a variety of methods and weighting schemes. A popular means of constructing a series of indexes over a period of years is to select one year as base, collect price and quantity data for all items covered by the index for the base year, and collect price data for all items for each year other than the base. The index for any year (I_n) can then be derived as follows:

where P_{in} = the price of item i in year n

Q_{ib} = the quantity of item i in the base year

P_{ib} = the price of item i in the base year.

Basic indexes of the type developed by the Department of Labor and the Department of Commerce are frequently combined with other indexes to form a composite index, each individual index being weighted by assumed contribution to price. This practice is particularly prevalent in military applications. Most military applications are concerned with price indexes over time; however, published indexes are available in AR 415-17 for construction costs by geographic area (Washington, D.C. = 100).[2]

The basic and composite indexes referred to above rest on an empirical base, i.e., historical price and quantity data have been used somewhere in index construction. These differ in character from projected price indexes (inflation indexes) that are intended to extrapolate from prices or costs in today's dollars to those of some year(s) in the future.

APPLICATION

The construction of a composite price index is illustrated by reference to a GRC study on ground based surveillance radars.[3] Hypothetical data are employed to illustrate adjustment of cost by a price index.

The GRC composite index was derived from separate indexes for (a) nonproduction labor, (b) production labor, (c) metals and metal products, and (d) electrical equipment. Each basic index was given an

equal weight (25%) and composite indexes were developed for the years 1956 to 1966 with 1966 as base. An excerpt from the radar composite index is provided in Table 11.

The derivation of the composite index is straightforward. For any given year each separate index (1966 base) is multiplied by the common weighting factor of .25 and the individual results added to form the composite index. Simple adjustments were made to two of the original separate indexes to convert them from an average 1957-1959 base to a 1966 base. This was accomplished by adjusting the original index for a given year by the index for 1966. As can be seen in the metals and metal products index, this made the revised index for 1966 equal to 100 (108.3/108.3) and that for 1965 equal to 97.6 (105.7/108.3).

Table 12 shows hypothetical price data by year for three ground combat surveillance radars. Column 3 shows actual prices and column 4 shows the prices adjusted to 1966 dollars.

The GRC composite indexes for 1965, 1964, and 1959 (with suitable repositioning of the decimal point) were exployed respectively to adjust prices to 1966 for radars, A, B, and C as follows:

Radar A price (1966) = \$20,000 x .966 = \$19,320
Radar B price (1966) = \$15,000 x .947 = \$14,205
Radar C price (1966) = \$12,000 x .875 = \$10,500

Limitations

Price indexes are based on sample data and thus have the common errors associated with sampling. Further, there is the problem of homogeneity of data—a problem present also in CER development. The problem becomes particularly acute when indexes are developed for years far from the base period. Over a long period there are significant changes in quality and an index tends to commingle the effects of quality and price change.

Military indexes are generally developed from commercial indexes. Commercial experience does not always parallel military experience. Hence, developed military indexes may inadequately reflect economic conditions in the military sector. A military price index should never be confused with an index of cost growth. The price index measures economic changes. Cost growth is a result of noneconomic factors as well as economic.

Table 11

PRICE INDEX SERIES FOR AEROSPACE DEVELOPMENT AND PRODUCTION

	1966	1965	1964	1963	1962	1961	1960	1959	1958	1957	1956
LABOR:											
NON-PRODUCTION (Scientists & Engineers)											
Mean Monthly Salary (Ref. 7)	1081.1	1028.8	1016.1	980.4	895.3	866.3	821.9	800.3	754.2	696.7	653.9
Index (1966 = 100)	100.0	95.2	94.0	90.7	82.8	80.1	76.0	74.0	69.8	64.4	60.5
Weighted Index (25%)	25.0	23.8	23.5	22.7	20.7	20.0	19.0	18.5	17.5	16.1	15.1
PRODUCTION											
Hourly Wage (Ref. 8 & 9)	3.29	3.16	3.02	2.95	2.87	2.77	2.70	2.62	2.50	2.35	2.27
Index (1966 = 100)	100.0	95.4	91.8	89.7	87.2	84.2	82.1	79.6	76.0	71.4	69.0
Weighted Index (25%)	25.0	23.9	23.0	22.4	21.8	21.1	20.5	19.9	19.0	17.9	17.3
MATERIALS:											
METALS & METAL PRODUCTS											
Index (1957-1959 = 100, Ref. 10)	108.3	105.7	102.8	100.1	100.0	100.7	101.3	101.2	99.1	99.7	97.0
Index (1966 = 100)	100.0	97.6	94.9	92.4	92.3	93.0	93.5	93.4	91.5	92.1	90.3
Weighted Index (25%)	25.0	24.4	23.7	23.1	23.1	23.3	23.4	23.4	22.9	23.0	22.6
ELECTRICAL EQUIPMENT											
Index (1957-1959 = 100, Ref. 10)	99.0	96.8	96.8	97.4	98.4	100.0	101.3	101.7	100.2	93.1	91.1
Index (1966 = 100,	100.0	97.8	97.8	98.4	99.4	101.0	102.3	102.7	101.2	99.1	92.0
Weighted Index (25%)	25.0	24.5	24.5	24.6	24.9	25.3	25.6	25.7	25.3	24.8	23.0
COMPOSITE INDEX	100.0	96.6	94.7	92.8	90.5	89.7	88.5	87.5	84.7	81.8	78.0

Table 12

HYPOTHETICAL PRICE RATES

(1) Radar type	(2) Year of purchase	(3) Price $ (year of purchase)	(4) Price $ (1966)
A	1965	20,000	19,320
B	1964	15,000	14,205
C	1959	12,000	10,500

Historical price indexes rest on empirical justification. The propriety of using empirically derived indexes to adjust historical cost data is universally recognized. On the other hand, considerable controversy exists on the propriety of using projected indexes to convert to future year dollars. Any justification for such projected indexes ultimately rests on the capability to reasonably forecast future economic conditions.

CITED REFERENCES

1. Dept of Army, "Economic Analysis and Program Evaluation of Resource Management," AR 37-13, 6 April 1963, pp 2-4 to 2-5.

2. Dept of Army, "Empirical Cost Estimates for Military Construction and Cost Adjustment Factors," AR 415-17, 26 June 1972.

3. General Research Corporation, "Cost Estimating Methods for Ground Combat Surveillance Radars," April 1968, pp 60-66.

OTHER REFERENCES

1. C. A. Batchelder et al, "An Introduction to Equipment Cost Estimating," RM-6103-SA, The RAND Corporation, December 1970, pp 23-30.

2. Frederick E. Croxton and Dudley J. Cowden, <u>Applied General Statistics</u>, Prentice-Hall, Inc., New York, 1939, Chaps 20-21.

3. Larry Guerrero and Gerald W. Kalal, "Historical Inflation Indices Cost Research Report," AMSWE-CPE 73-9, US Army Weapons Command, May 1973.

B.3 BENEFIT DETERMINATION

PURPOSE

An economic analysis always has a cost side and, except for strictly cost-saving proposals, also has a benefit side. The preferred system alternative can only be determined by considering both the costs and benefits of all competing alternatives. The selection of the preferred alternative is facilitated to the extent that benefits can be expressed in dollar terms. This places different benefits on a common footing. The advantages can be appreciated by considering the difficulties that might arise from having costs expressed in manhours, pounds of materiel, square footage of real property, etc. rather than in terms of dollars.

The decision maker can evaluate an economic analysis where all benefits have been properly quantified in dollar terms. In most analyses, however, dollar quantification will not be found feasible for all benefits. Every attempt should be made to quantify such benefits in terms of meaningful physical or performance measures. Those benefits that defy any type of quantification must be described narratively. The narrative descriptions must be clear enough and in sufficient detail to permit the decision maker to assign judgmental values of worth.

DESCRIPTION

The benefits produced by a system represent the return on resources expended. Benefits can be either direct in the sense that they measure accomplishment of system objectives or indirect, reflecting, for example, reduced requirements for resources in related activities. Where possible, benefits are quantified in terms of dollars, thus permitting direct

comparison with costs. Certain benefits, however, can be quantified only in terms of physical or performance measures. Others, such as morale, may be described only in verbal terms.

The statement of system objectives provides the point of departure for benefit determination. The generalized goals included in this statement must be translated into specific, quantifiable system functions. A platform for measuring benefits of proposed benefits is best achieved by first listing the output characteristics and any known deficiencies of the existing system. If certain outputs are common to <u>all</u> system alternatives, these can often be excluded from the eco nic analysis.

Table 13 depicts the process of benefit determination in oversimplified form. It stresses the fact that the steps of identifying and describing outputs are common to and essential parts of any type of benefit determination.

Table 13

BENEFIT DETERMINATION

Identify output	Describe output	Develop/apply workload measure	Develop/apply workload-related cost factor	Type of Benefit
x	x			Qualitative
x	x	x		Nondollar quantitative
x	x	x	x	Dollar quantitative

APPLICATION

Combat Service Support System (CS_3)[1]

Economic analyses of the CS_3 present system benefits of three general types—dollar quantifiable, nondollar quantifiable, and other (i.e., qualitative) benefits. An example of each together with basis of calculation and/or source is provided below. General description and comments on the CS_3 benefit analyses are provided in the CS_3 Case Study (Vol IV).

Dollar-Quantifiable Benefit. One of the purported benefits of the CS_3 supply subsystem over the existing card-processor system was the provision of expanded editing capability. This additional capability would allow more extensive editing of supply requisitions. The editing would reduce the number of erroneous requisitions processed and would effect dollar savings by eliminating the administrative and processing costs involved in error correction. The factors used in calculating annual dollar savings (CS_3 over the existing system) with factor source are provided in Table 14.

Table 14

BENEFITS-MONTHLY DOLLAR SAVINGS

Factor	Value	Source
Number of requisitions per month	47,206	CS_3 division-level test data
Percent reduction in erroneous requisitions	5%	Expert opinion (Test Hq, III Corps and HQDA Panel)
Cost to recover from erroneous requisition	$4	Expert opinion (Test Hq, III Corps and HQDA Panel)

Monthly dollar savings were estimated from the above factors and extended to a yearly basis as follows:

47,206 x .05 x $4 x 12 = $113,280 or rounded $113K

Nondollar-Quantifiable Benefit. The CS_3 division-level test results were used to identify certain benefits of CS_3 over the existing system that were quantifiable but not capable of being translated into dollar terms. An example of such a benefit is the capability of the CS_3 personnel and administration (P&A) subsystem to execute a greater workload than the existing P&A card-processor system while utilizing 36 percent less machine time.

Other (Qualitative) Benefit. A prepared list of nonquantifiable benefit activities was provided to a HQDA Panel for evaluation purposes. The panel decided activity by activity whether CS_3 with teleprocessing performed better than, equally as well as, or poorer than two baseline alternatives—CS_3 without teleprocessing and the existing card-processor system. Stated in the most conservative terms, the panel judged that for each activity the CS_3 with teleprocessing afforded nonquantifiable benefits at least as great as those from the other two alternatives. Examples of nonquantifiable benefit activities follow:

a. Insures fund availability prior to submission of requisitions.

b. Produces supply study and performance statistics.

c. Provides weekly data on personnel assets not assigned to specific units.

d. Lists personnel actions during the coming month.

"Cold-Iron" Support[2]

A Naval Facilities Engineering Command (NAFAC) study of cold-iron support (provision of berthing and shore-based utilities) to ships provides the classic case of proper use of nondollar benefit analysis and benefit/cost ratios. The Defense Economic Analysis Council (DEAC) has reproduced a presentation on the cold-iron support study in its "Benefit/Output Compendium." Salient points of the presentation follow.

NAVFAC was faced with the task of selecting $28 million worth of cold-iron support military construction projects from a potential program of $150 million for implementation in FY73. On a priori grounds the potential payoff from cold-iron support investment was concluded to

derive from three sources:

a. Increase in liberty man days (LMDs), i.e., in the days the crew can be freed from ship-duty assignment.

b. Savings resulting from lower operating and maintenance costs of utilities.

c. Decrease in maintenance backlog.

During the course of the study it was found that cold-iron support did little to alleviate problems of accrued maintenance, and maintenance considerations were dropped from further analysis. Utility cost savings were treated as offsets to project investment costs, leaving the additional LMDs generated by the project as the sole benefit measure. The effectiveness of each project was determined by calculating the cost per additional LMD, where cost represented the sum of project investment and the change in total life cycle operating costs. A priority listing of $28 million worth of projects was selected on the basis of the effectiveness or benefit/cost ratio. Benefit/cost ratios could be used for this purpose since the projects did not represent mutually exclusive alternatives.

LIMITATIONS

Benefits must be determined in a comprehensive and consistent manner. That is, all benefits must be considered and double counting avoided. No activity should be included under two benefit elements or be reflected in both benefit and cost. For example, reduced manhours should not be cited as a benefit for an alternative if the manhours enter into determination of system operating costs.

An economic analysis that does not provide full documentation of benefit calculations falls short of its mission. Full documentation includes rationale, calculating methodology, and basic data sources. Best judgment or consensus values should be explicitly identified (as in the CS_3 analysis) so that the decision maker can take this into account.

Dollar quantification should be attempted where logic and data permit. While it may not be possible to attain a complete empirically-based set of dollar benefits, every effort should be made in this direction. The analyst should proceed with subjectively determined dollar

values or factors with extreme caution. Otherwise, the analyst may be imposing his "utility function" on the decision maker via the study results.

CITED REFERENCES

1. "Combat Service Support System," This Handbook, Vol IV, Chap. 2.

2. LTJG C. Robert Kidder, "The Cold Iron Study: An Application of Output Measurement in Economic Analysis," in Benefit/Output in Economic Analysis in the Department of Defense, pp 43-54.

OTHER REFERENCES

1. Dept of Army, "Economic Analysis and Program Evaluation of Resource Management," AR 37-13, 6 April 1973, pp 2-5 to 2-6.

2. Dept of Army, Office of the Adjutant General, Ltr, subject: "Economic Analysis of Proposals Supported by Automated Data Systems," 25 January 1972, pp 7-9.

3. Munitions Command, Office of the Comptroller, Cost Analysis Division, Economic Analysis Manual, March 1972, pp I-40 to I-43.

4. Rose Glubin, "Benefit/Output Determination—A Methodological Approach for the Practitioner," in Benefit/Output in Economic Analysis in the Department of Defense, Defense Economic Analysis Council, January 1973, pp 85-101.

B.4 ANALOGY COST ESTIMATING

PURPOSE

The analogy costing approach can be used to estimate the costs of any equipment item provided that technical specifications are available and that cost and technical specifications can be secured for a single comparable predecessor. The analogy approach is frequently used where it is not practicable to secure a large sample of past costs and technical data to generate reliable cost estimating relationships (CERs) through regression analysis.

Analogy costing provides a quick and inexpensive means of estimating costs compared to either the industrial engineering or CER approach (except where off-the-shelf CERs are available). As a result, the approach is useful for estimating low-cost-system components and for providing cost estimates in short-fuzed studies.[1,2]

DESCRIPTION

The distinguishing feature of the analogy approach lies in its heavy reliance on the costs and technical characteristics of a single historical equipment item. The first and most important step in deriving credible estimates for a "new" item consists of selecting a suitable counterpart "old" item. The second consists of selecting a proper technical characteristic to use as the analogy base.

The analogy approach typically assumes that cost is proportional to the magnitude of some technical characteristic; that is, for example, a doubling of weight is assumed to double cost. The following equation illustrates this case:

$$C_N = C_O \times W_N / W_O,$$

where C_N = cost of the new item
C_O = cost of the old item
W_N = weight of the new item (specification or estimate)
W_O = weight of the old item.

Variants of the simplified approach illustrated above remove the proportionality feature either by using empirically derived curves of cost ratios to technical characteristic ratios (AR 415-17[3]) or by introducing information on more than one item into the estimate. In both variants, information on the most comparable item continues to provide the primary basis for the analogy cost estimate.

APPLICATION

Petroleum, Oils, and Lubricants (POL) Cost Per Mile

This example is taken from a weapons system cost study[4] on the Austere Mechanized Infantry Combat Vehicle (MICV). POL costs for the Austere MICV were based on the experience data for the M551 General Sheridan—POL costs of $.0670 per mile. Adjustments were made to this experience data to account for the fact that the MICV was scheduled to have an eight cylinder engine, whereas the M551 was powered by a six cylinder engine. Details of computation have been reproduced from the study (p 21) and provided below.

The following relationship was used to estimate POL cost per mile for the MICV:

$$\frac{X_1}{X_2} = \frac{Y_1}{Y_2}, \text{ where}$$

X_1 = POL Cost/Mile M551 = $.0670

X_2 = #Cylinders in M551 Engine = 6

Y_1 = Estimated POL Cost/Mile MICV

Y_2 = #Cylinders in MICV Engine = 8

Employing the above factors, the following computations result:

$$\frac{\$.0670}{6} = \frac{Y_1}{8}$$

$$6Y_1 = \$.5360$$

$$Y_1 = \$.0893 = \text{Estimated POL Cost/Mile MICV}$$

LIMITATIONS

The limitations of analogy costing can be seen most clearly by contrasting the analogy approach to that of parametric costing (costing by CERs). The succeeding paragraphs from Ref 1 (p I-2-9) address the relative disadvantages of the approach vis-a-vis the use of CERs developed through regression analysis. It should be kept in mind that regression analysis is possible only where cost and technical data are available on several related historical items or systems.

The analogy approach invariably involves the relation of cost to a single explanatory variable. This is done because no theoretical basis for determining the simultaneous influence on cost of two or more explanatory variables by analogy has been put forth. Often cost can be explained better through use of more than one variable, and the more flex. .e CER approach thus has a comparative advantage over that of analogy.

The CER approach is a more conservative method of estimating than the analogy approach in that the former is based on an "average" of several observations. In the analogy approach a cost estimate is based only on the experience of a single observation. If the cost of an earlier system or equipment item reflects unusual circumstances, an analogy estimate of a new system or equipment item could be severely biased.

Another advantage of CERs over the analogy approach is that the statistics related to a CER give a reviewer some indication of the merit of the CER. Among the statistics are the coefficient of determination, standard error of estimate, and confidence intervals.

CITED REFERENCES

1. Alfred D. Stament and Carl R. Wilbourn, "Cost Estimating Relationships: A Manual for the Army Materiel Command," RAC-TP-449, Research Analysis Corporation, May 1972.

   Part I, Chap. 2 discusses the classical analogy approach and compares its relative advantages and disadvantages vs the CER approach. Appendix F describes a modified analogy approach whereby some of the advantages of CERs can be incorporated into analogy costing.

2. Dept of Army, Comptroller of the Army, "Costing Methodology Handbook," April 1971.

   A brief discussion of analogy costing is contained on pp 4-29 to 4-30. The discussion covers both uses and pitfalls.

3. Dept of Army, "Empirical Cost Estimates for Military Construction and Cost Adjustment Factors," AR 415-17, 26 June 1972.

4. LT W. A. Holman, "Annual Operating Costs of the Austere Mechanized Infantry Combat Vehicle (MICV)," WS-103-71, US Army Field Operating Cost Agency, November 1970. FOR OFFICIAL USE ONLY.

OTHER REFERENCES

1. C. A. Batchelder et al, "An Introduction to Equipment Cost Estimating," RM-6103-SA, The RAND Corporation, December 1970.

B.5 COST ESTIMATING RELATIONSHIP

PURPOSE

A CER can be used to estimate the costs of an activity or an equipment item provided that its technical characteristics are available. CERs can be used to estimate elements of research and development (R&D), nonrecurring and recurring investment, and operating costs. They are generally best suited for use in recurring investment and operating cost applications.

Properly developed and applicable CERs are crucial to the estimation of credible cost estimates for systems in the early stages of development. Proper development results from the selection of explanatory variables that are logically cost-driving, from care in data collection and adjustment, and from adherence to the governing statistical principles. A CER must contain explanatory variables for which values, or at least official specifications, are "knowable" early in order for the CER to be applicable to developmental systems. For many items weight may be closely associated with item cost, but may be known with sufficient accuracy only as the item nears production.

DESCRIPTION

A cost estimating relationship (CER) is a statistically-derived equation which relates the costs of an item or activity to one or more physical and performance characteristics. A CER is based on empirical cost and technical characteristics data and is generally derived by standard regression techniques.

A number of different regression analysis models can be used to develop CERs. If no particular functional form is suspected by the

analyst, a simple linear regression model is often used. The equation of this model is

$$Y = a + bX$$

where Y is the dependent (cost) variable and X is the independent (explanatory) variable. Where the data warrants, multiple linear regression models can be used such as

$$Y = a + b_1X_1 + b_2X_2 + \dots b_nX_n$$

permitting a number (n) of independent variables to enter the predictive equation. Nonlinear regression models can also be used. Common examples are logarithmic-linear (log-linear) and logarithmic-logarithmic (log-log).

APPLICATION

Appendix B of RAC-TP-449 documents several weapon system oriented CERs.[1] For the most part the CERs are products of the Army Materiel Command (AMC) in-house or contract-supported efforts.[2] The CER inventory also contains CERs developed by or for other Army or Department of Defense (DOD) elements considered of possible use to AMC. Partial documentation of a CER developed by the Aviation Systems Command (AVSCOM) in report TR-C/A 1-68 follows:[3]

CER	$Y = 17.38 + 43.61X$ where Y = pounds of POL per flying hour for JP-4 us 's X = maximum allowable gross weight in thousands of pounds
Statistics	Sample size = 3 (OH-6A, UH-1, CH-47) Coefficient of correlation = .994 Range of maximum allowable gross weight = 2.4 (000) to 33.0 (000) lb

LIMITATIONS

No matter how careful a developer is in properly generating his CER and related statistics, he is usually at the mercy of the quality of the data at hand. This is so because the data are not ordinarily originated by the developer but instead are appropriated from sources often meant for purposes other than cost estimating. This type of quality limitation is a result of the integrity of the data.

Another type of qualitative limitation is one that arises when the sample data have characteristics that differ importantly from items for which cost estimates are wanted in the future. Technology changes, in particular, can make developed CERs virtually useless. The technological advances within the electronics industry provide some illustration. Here there have been successive changes from tubes to transistors and finally to integrated circuits.

Quantitative limitations of sorts are provided for a CER by its related statistics such as the coefficient of correlation and standard error of estimate. Statistics, however, provide only a partial measure of the range for which the CER is valid. A particular range of values for each of the independent variables and the dependent variable is inherent in the developed CER. Although the fitted curve may perform well within these ranges, little evidence is available to suggest how well it will perform beyond.

Frequently predictions of cost are wanted for items that lie outside the sample limits in terms of independent variable measurements. It is important to realize that such predictions are subject no only to statistical uncertainty but also to uncertainty about whether the appropriate type of curve is being used.

CITED REFERENCES

1. Alfred D. Stament and Carl R. Wilbourn, "Cost Estimating Relationships: A Manual for the Army Materiel Command," RAC-TP-449, Research Analysis Corporation, May 1972, Parts I and II.

2. US Army Materiel Command, Office of the Comptroller, "CER Compendium—Army Weapon and Equipment Systems," August 1972.

3. Stuart Epstein, "Petroleum, Oil and Lubricants Cost Estimating Relationship," TR-C/A 1-68, US Army Aviation Systems Command, 15 January 1968 (updated 3 July 1968).

OTHER REFERENCE

1. C. A. Batchelder, et al, "An Introduction to Equipment Cost Estimating," RM-6103-SA, The RAND Corporation, December 1970, Sections II-IV.

B.6 INDUSTRIAL ENGINEERING COST ESTIMATING

PURPOSE

The industrial engineering cost approach is used primarily to estimate hardware production costs and involves the consolidation of separately developed cost estimates formed from detailed analyses of work processes, material, and item dimensions. The approach is feasible only when technical data packages and drawings are in hand; it cannot be used to estimate costs of production for weapon systems in the conceptual stage.[1,2]

DESCRIPTION

The industrial engineering approach involves the division of the production process into component production segments. Each of these segments is then analyzed in terms of its labor and material requirements. This analysis is facilitated by the use of derived or published engineering standards.

In the engineering approach the direct costs of production are calculated for each production segment by applying current cost factors to the estimated labor and material requirements. Typically, overhead and assembly costs are based on the production segment resource requirements and/or estimated costs. Such diverse costs as tool maintenance, quality control, and manufacturing research in certain applications may ultimately relate back to the basic direct labor estimates.

One aerospace firm is reported to judge that the use of the industrial engineering approach for airframe cost estimating entails preparation of some 4500 component estimates. For this reason the firm avoids its use whenever possible.[3] The use of the approach, even

where substantially fewer estimates are involved, will always be found to be more expensive than analogy costing and generally more so than estimating by cost estimating relationships (CERs).

Industrial engineering cost estimates are based on the specific production processes and materials, on the particular producer and his location, and on the production equipment available to produce the items of equipment. With all this specific information, it seems reasonable to expect the detailed approach to produce more accurate estimates than less costly methods (e.g., CERs). The use of the approach generally reduces to an expressed or implied presumption of greater accuracy.[1] At least one authority disputes this presumption, indicating that the industrial engineering approach is bound to leave some costs unestimated.[3]

APPLICATION

Table 16 illustrates how the direct labor costs for manufacturing a steel center bracket might be estimated using the industrial engineering approach. The extent of detailed costing depicted therein for calculating the direct labor costs of a relatively minor production segment lends support to the assertion that use of the approach for airframe costing might entail generation of over 4500 separate cost estimates (see previous section).

Table 15 is reproduced from Ref 3 (p 4) and represents an adaptation of one originally published in Alford.[4] The surrounding text from Ref 3 (p 2) follows.

> Table 15 illustrates the detail required at the lowest level of estimating; in this case a labor cost estimate for forming a steel center bracket. The name and number of the operations and the machines that will be used are given with estimates of setup and operating time and labor cost. When they exist, standard setup and operating costs are used in making estimates, but if standards have not been established (which is frequently the case in the aerospace industry), a detailed study is made to determine the most efficient method of performing each operation.

Table 15

DETAILED LABOR COST ESTIMATE FOR FORMING A STEEL CENTER BRACKET

				Setup Charges			*Operating Labor*		
Depart-ment	*Operation Number*	*Operation*	*Machine*	*Hours*	*Rate ($)*	*Cost ($)*	*Output per Hour*	*Rate ($)*	*Cost per 1000 ($)*
20	16241	Setup	Niagara 462	1/2	3.40	1.70			
20	16081	Shear to length	Niagara 462				3000	3.40	1.13
20	16242	Setup	No. 4 Bliss press	2/3	3.40	2.27			
20	11571	Perforate and blank	No. 4 Bliss press				1100	3.30	3.00
20	16243	Setup	No. 4 Bliss press	1	3.40	3.40			
20	12951	Form	No. 4 Bliss press				450	3.30	7.26
18	14351	Tap	Tap wheel				900	3.15	3.47
18	16244	Setup	Plain mill	1/2	3.40	1.70			
18	14661	Mill slots	Plain mill				100	3.40	34.00
18	15541	File burrs	Hand file				95	3.40	35.70
07	15245	Setup	Speed lathe	1/4	3.40	.85			
07	11542	Burr 6 slots (and mill)	Speed lathe				600	3.15	5.26
07	16246	Setup	Multiple drill	1/2	3.40	1.70	900	3.15	3.47
07	11941	Countersink 2 holes	Multiple drill						
07	16247	Setup	Tapping machine	1/2	3.40	1.70			
07	16561	Tap 2 holes	Tapping machine				400	2.75	6.88
19	15151	Dull nickel plate					1000	3.50	3.50
						13.32			103.67

NOTE: This table is adapted from a detailed labor cost estimate published in L. P. Alford and John R. Bangs (eds.), *Production Handbook*, The Ronald Press Company, New York, 1953, p. 1045.

LIMITATIONS

Industrial engineering cost estimates are time-consuming and expensive relative to costing by analogy or CERs. The industrial engineering approach also is less flexible than the other two methods in that its use is limited to items either in or near production.

An engineering cost estimate is constructed by aggregating numerous detailed estimates. There is always the danger that one or more elements will be overlooked and hence lead to an underestimate of costs. The less closely associated the estimator is with the particular production item, the more likely that elements will be overlooked. This is one reason that the approach might meet with more success at the corporate level than in Governmental cost studies.[2]

A limitation of the approach relative to costing by CERs is "that the statistics related to the CER give some indication of the credence to be placed on the estimate. Summary figures of merit are more difficult to generate for the industrial engineering estimate. The reviewer of an industrial engineering estimate thus has a much more difficult job of evaluation than the reviewer of a CER estimate.[1]

CITED REFERENCES

1. Alfred D. Stament and Carl R. Wilbourn, "Cost Estimating Relationships: A Manual for the Army Materiel Command," RAC-TP-499, Research Analysis Corporation, May 1972.

2. Dept of Army, Comptroller of the Army, "Costing Methodology Handbook," April 1971.

3. C. A. Batchelder et al, "An Introduction to Equipment Cost Estimating," RM-6103-SA, The RAND Corporation, December 1970.

4. L. P. Alford and John R. Bangs, Production Handbook, The Ronald Press Company, New York, 1953.

OTHER REFERENCES

1. Dept of Army, US Army Materiel Command, "'Should-Cost' Analysis Guide," AMCP 715-7, November 1970.

2. Fred C. Hartmeyer, Electronics Industry Cost Estimating Data, The Ronald Press Company, New York, 1964.

B.7 SENSITIVITY/CONTINGENCY ANALYSIS

PURPOSE

Cost/benefit analysis is future oriented and as a result it must be conducted with imperfect information, best guesses, and assumptions that are not susceptible to complete justification. It is the analyst's task to assess the major areas of uncertainty, determine those that impact most heavily on the choice among alternatives, and conduct the appropriate sensitivity, contingency, or other types of analysis accordingly.

The basic purpose of sensitivity and contingency analysis is to inform the decision maker on how the various alternatives measure up to one another for both the original set of factor values and assumptions and for reasonable changes thereto.

DESCRIPTION

Sensitivity analysis and contingency analysis constitute two of the classical approaches to the problems of uncertainty. Uncertainty also can be addressed partly by statistical means and partly by the manner in which basic assumptions are formulated. Statistical measures are usually associated with the estimation of cost factors or cost estimating relationships (CERs) and take the form of correlation coefficients and confidence intervals. A fortiori analysis—generally the adoption of assumptions uniformly favorable to the existing system where matters of uncertainty are involved—is used to facilitate a conservative cost/benefit analysis. If the proposed system alternative appears preferable to the existing system under such a set of assumptions, any other set would only reinforce the preference.

Sensitivity analysis provides a guide to the reliability of the ranking of alternatives by assessing the impact on system alternative costs and benefits that result from changes in system parameters, operating rates, basic cost factors, and the like. Sensitivity analysis addresses the quantitative aspects of uncertainty in that it involves iteration of calculations using different quantitative values for the variables of interest.

Contingency analysis addresses elements of uncertainty that cannot be attributed to variations in individual factor values. It is qualitative in the sense that it does not address such factors but instead involves assessment of major changes in the underlying ground rules and assumptions of the analysis. For example, a contingency analysis might address the effect on study results of increased civilianization of base operations activities, passage from a wartime to a peacetime environment, continuation of existing environmental policies vs institution of more stringent ones, etc.

APPLICATION

Sensitivity Analysis

Chapter 2 of the DepotMAIDS Case Study documents the use of sensitivity analysis in a real life economic analysis application (see Vol IV).[1] One of the important determinants of relative cost between an existing manual and a proposed computer-assisted engine overhaul system was found to be the diagnostic candidacy rate of field assets, that is, the percent of machine-processable engines forwarded separately from vehicles. The best estimate was that the future diagnostic candidacy rate would be 20%; past experience heavily weighted by Vietnam activities suggested a diagnostic rate of 12.5%. Lowering the candidacy rate from 20% to 12.5% was found to produce a decrease in the savings/investment (S/I) ratio of less than 0.2.

Chapter 2 of the CS_3 Case Study (see Vol IV) exemplifies use of contingency analysis. In one of the CS_3 studies, analysis was made of the costs of fielding alternative CS_3 systems with and without assumption of budget constraints imposed by the planned CS_3 annual procurement funding programs for the FY72-FY75 time frame. These constraints, in

conjunction with (a) the CS_3 implementation schedules and (b) the necessity to procure the requisite CS_3 support equipment (vans, air conditioners, etc.) from contractors, were used to determine the amount of remaining procurement funds available for purchase of CS_3 main frames and peripherals. Priority of purchase over lease had been determined on the basis of a previous purchase/lease analysis.

Removal of the budget constraint assumption and the consequent shifting from lease to purchase resulted in decreasing the total present value costs of the CS_3-without-teleprocessing alternative by 2 percent and of the CS_3-with-teleprocessing alternative by 4 percent. The contingency analysis (loosely referred to in Vol IV as sensitivity analysis) showed that the preferred teleprocessing alternative became even more so when budget constraint considerations were dropped.

LIMITATIONS

Sensitivity and contingency analysis provide useful information to the extent that they address reasonable alterations in factors and assumptions. Thus, the common practice of conducting a sensitivity analysis with a pessimistic, optimistic, and most likely value is commendable, provided that real thought has gone into establishing the two extreme values. Analyses that track the impact on results of arbitrary changes in factor values are of more limited usefulness.

Sensitivity and contingency analyses are most useful where they address considerations that potentially might alter the relative ranking of system alternatives. Even though a particular factor or assumption may be surrounded with considerable uncertainty, it may be given low priority when it is judged that the uncertainty would effect the costs and/or benefits of all alternatives to roughly the same degree.

The analyst can never assume that the results of a sensitivity/contingency analysis are self-explanatory. Computer printouts should ordinarily be viewed as the raw material for presenting results rather than the presentation itself. More important, the analyst must never confuse the conduct of sensitivity/contingency analysis with the more basic task of generating feasible alternatives for study.

CITED REFERENCE

1. This Handbook, Vol IV.

OTHER REFERENCES

Dept of Army, Office of the Adjutant General, Ltr, subject: "Economic Analysis of Proposals Supported by Automated Data Systems," 25 January 1972, pp 10-11.

Munitions Command, Office of the Comptroller, Cost Analysis Division, Economic Analysis Manual, March 1972, Chapter VII.

William H. Sutherland, "A Primer of Cost Effectiveness," RAC-TP-250, Research Analysis Corporation, March 1967, Chapter 4.

Appendix C

STATISTICAL TECHNIQUES

C.1 SCATTER DIAGRAM

PURPOSE

A scatter diagram graphically portrays the relation of one variable (often a cost variable) to that of another (often a physical or performance characteristic). The scatter diagram assists in selecting visually the most pertinent form of mathematical relation between the two variables and is usually used as a screening device in regression applications.

GENERAL DESCRIPTION

A scatter diagram is constructed by plotting the coordinates of paired observations on grids. Three types of grids can be used—arithmetic, semilogarithmic, or double logarithmic. Examples and discussions of simple diagrams constructed on these grids are described in this section. The sample applications of the following section show how additional information can be introduced in two-dimensional diagrams.

Equal distances along an arithmetic scale represent equal absolute differences; equal distances along a logarithmic scale represent equal relative differences. Figure 23 shows how the numbers 1 to 4 are related on the two scales.

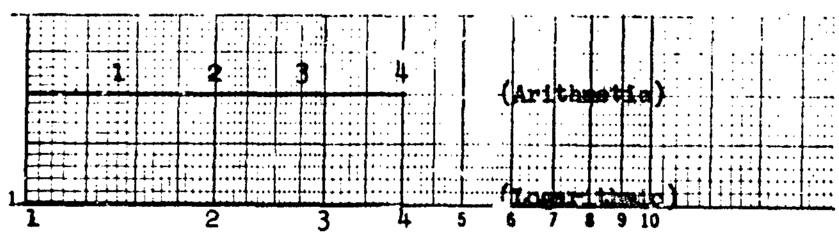

Fig. 23—Illustration of Arithmetic and Logarithmic Scales

Arithmetic Grid Diagram

Most scatter diagrams are of this type. To prepare such a diagram the analyst simply plots paired dependent and independent variable observations in original form on standard graph paper. Diagram A of Fig. 24 shows the plotting of five paired observations and a free-hand drawing of a linear relation between the variables. The paired

observations of the dependent (Y) variable and independent (X) variable are as follows:

Y	X
45	40
60	70
35	30
30	20
60	60

Diagrams B to D of Fig. 24 show three additional scatter diagrams together with their underlying mathematical relations. Ezekiel[1] (Chap. 6) displays and discusses a variety of two-variable relations including quadratic and cubic. Analysts should familiarize themselves with the various forms in order to make best use of scatter diagrams in regression applications. With respect to Fig. 24 it should be noted that all constants in the diagrams have a positive sign. The diagrams were constructed this way solely to facilitate preparation.

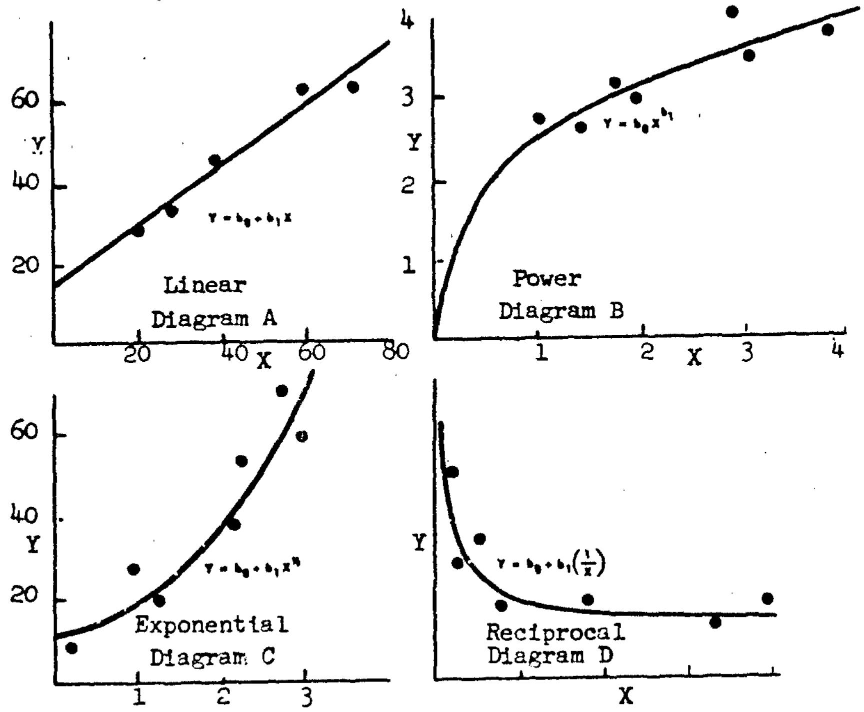

Fig. 24—Sample Scatter Diagrams: Arithmetic Grids

Semilogarithmic Grid Diagram

Semilog graph paper contains a vertical logarithmic scale and a horizontal arithmetic scale. Plotting of Y and X observations in original form on such paper is equivalent to plotting log Y and original X observations on arithmetic paper. The special paper simply relieves an analyst from taking logarithms of th dependent variable observations. A scatter diagram that suggests a linear relation under either of the above plotting approaches perforce suggests an exponential relation between the variables in original form. Thus, Diagram B of Fig. 25 is the semilog counterpart of Diagram C of Fig. 24.

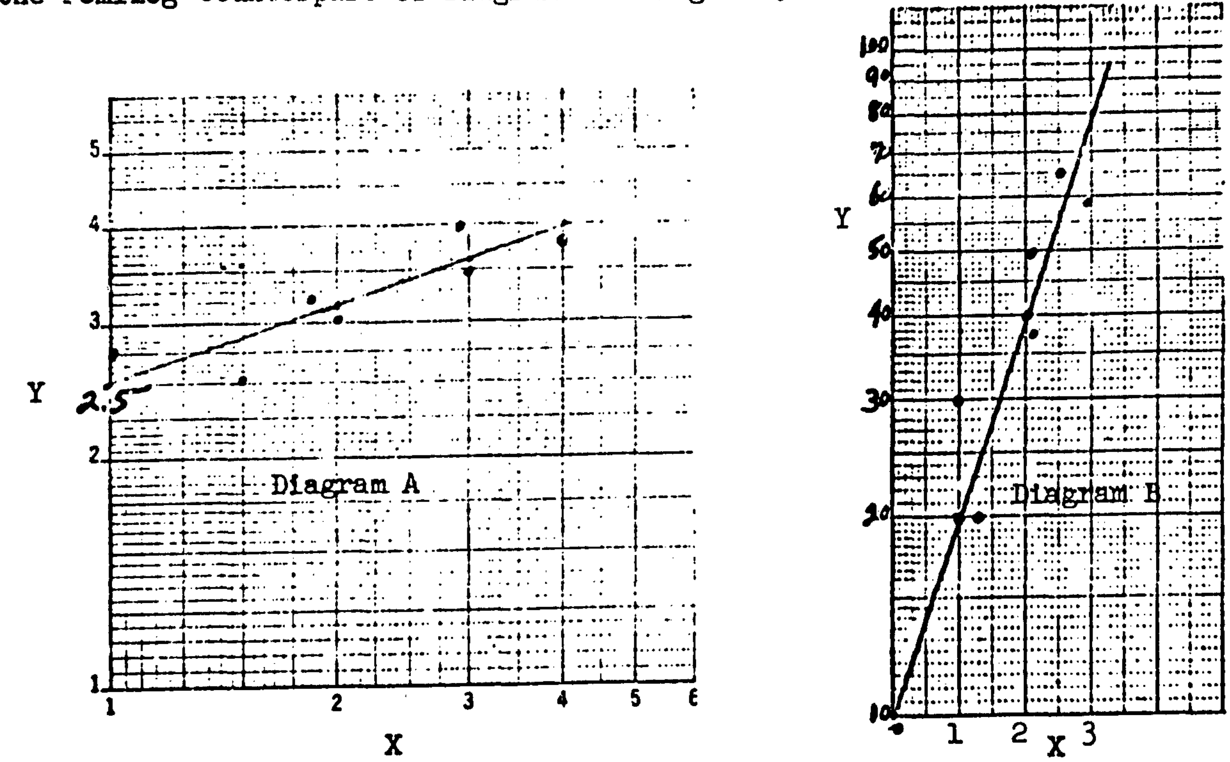

Fig. 25—Sample Scatter Diagrams: Double Log and Semilog Grids

Double Logarithmic Grid Diagram

Double log graph paper contains a logarithmic scale on both axes. Plotting of Y and X observations in original form on such paper is equivalent to plotting the logarithms of the original Y and X observations on arithmetic paper. The use of special log graph paper can save the analyst considerable time. A scatter diagram that suggests a linear relation under either of the above plotting approaches perforce suggests a power relation between the variables in original form. Thus, Diagram A of Fig. 25 is the double log counterpart of Diagram B of Fig. 24.

APPLICATION

Fuel Consumption

Chapter 3 of RAC-TP-451[2] presents costs of fuel consumption for various equipment classes. The early investigations of fuel consumption were facilitated by the preparation of rough scatter diagrams of fuel consumption per mile or hour against equipment weight. Separate diagrams were constructed for trucks, tracked vehicles, and aircraft. Special symbols were used to plot the observations for different engine types. Regressions were then run accordingly.

A scatter diagram used in Ref 2 as part of the final documentation is reproduced as Fig. 26. The figure shows the raw observations of fuel consumption per mile for tracked vehicles with diesel engines (●) and with gasoline engines (▲). Also the figure shows the regressions developed from the exhibited data.

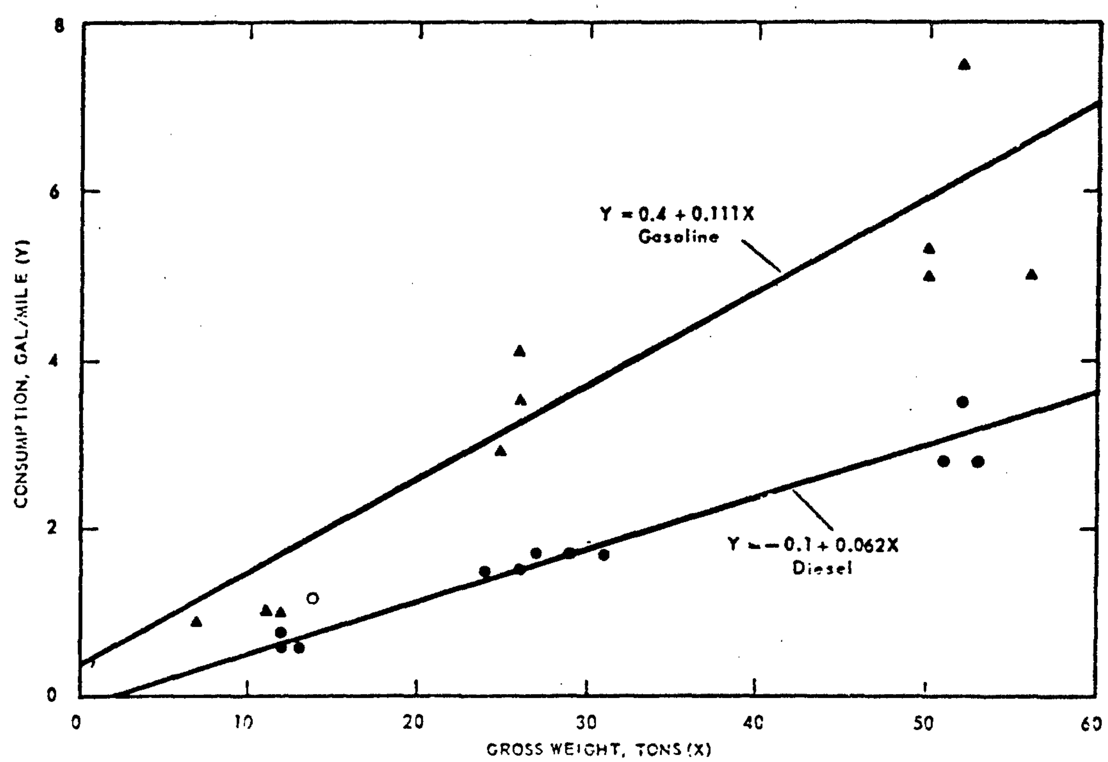

Fig. 26–Fuel Consumption as a Function of Weight, Tracked Vehicles

LIMITATIONS

Scatter diagrams can be helpful in deriving valid regressions provided that they are tempered by logic. Without the support of logic, nonsense regressions can result. The problem is that the illogic of the regression might escape the developer and be used. To avoid this, the developer must assess the logical relationship between variables before beginning to plot. At a minimum the developer should have a supportable opinion on the direction of change (increase or decrease) in the dependent variable associated with a change in the independent variable.[3]

CITED REFERENCES

1. M. J. B. Ezekiel and K. A. Fox, Methods of Correlation and Regression Analysis, John Wiley & Sons, Inc., New York, 1959, 3d ed.

2. Doris C. Berger, John O'Flaherty, and Joseph String, Jr., "Selected Uniform Cost Factors: A Manual for the Army Materiel Command," RAC-TP-451, Research Analysis Corporation, June 1972.

3. Alfred D. Stament and Carl R. Wilbourn, "Cost Estimating Relationships: A Manual for the Army Materiel Command," RAC-TP-449, Research Analysis Corporation, May 1972.

OTHER REFERENCE

1. Dept of Army, Comptroller of the Army, "Costing Methodology Handbook," April 1971.

C.2 REGRESSION ANALYSIS

DEFINITION

Regression analysis is a method by which functional relationships between a dependent variable and a set of independent variables are estimated statistically.

DESCRIPTION

The objective of regression analysis is to estimate from historical data the straight line that best fits the data. The meaning of the term "best fit" is derived from the fact that the least squares regression model determines the line through the set of points that has the least variation with respect to these points. The variation is measured by the sum of the squares of the vertical difference between each data point and the line itself. Figure 27 illustrates this point

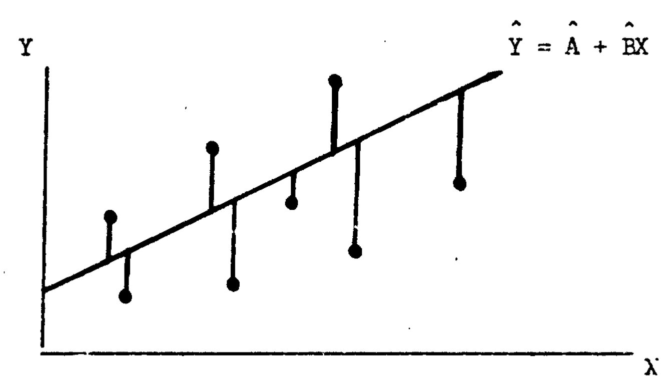

Fig. 27 —Deviations Around the Regression Line

The vertical lines between the data points and the regression line represent the deviations. The symbol ˆ is used over the Y, A, and B terms to indicate that the regression line $\hat{Y}$ and the parameters $\hat{A}$ and $\hat{B}$ are estimated from the data.

The regression equation for the simple term variable linear model is

$$\hat{Y} = \hat{A} + \hat{B}\, Y$$

where $\hat{A}$ is the estimated Y intercept and $\hat{B}$ is the estimated slope of the regression line.

The objective is to estimate values of $\hat{A}$ and $\hat{B}$ from actual data. The formulae for estimating $\hat{A}$ and $\hat{B}$ are as follows.

$$\hat{B} = \frac{\sum_{i=1}^{n} X_i\, Y_i - \left(\sum_{i=1}^{n} X_i\right)\left(\sum_{i=1}^{n} Y_i\right)}{\sum_{i=1}^{n} X_i^2 - \frac{\left(\sum_{i=1}^{n} X_i\right)^2}{n}}$$

$$\hat{A} = \frac{\sum_{i=1}^{n} Y_i}{n} - \hat{B}\,\frac{\sum_{i=1}^{n} X_i}{n}$$

APPLICATION

Suppose we wish to estimate the relationship between fuel consumption and horsepower of military land vehicles using regression analysis.

First, we hypothesize that fuel consumption is a function of horsepower and has a linear relationship which can be represented by the line

$$Y = A + B\, X$$

Also, assume that we have collected data on 10 observations from similar land vehicles with different horsepowers. The data are presented in Table 16.

Substituting in the formulae we obtain

$$\hat{B} = \frac{34{,}480 - \frac{(2465)\ (149)}{10}}{646{,}425 - \frac{(2465)^2}{10}}$$

$$= \frac{-\ 2248.5}{38{,}802.5}$$

$$= -\ .0579$$

$$\hat{A} = \frac{149}{10} - (-.0579)\ \frac{2465}{10}$$

$$\hat{A} = 14.9 + 14.27$$

$$= 29.172$$

The estimated equation is

$$\hat{Y} = 29{,}172 - .0579\ X$$

and is given in Figure 28.

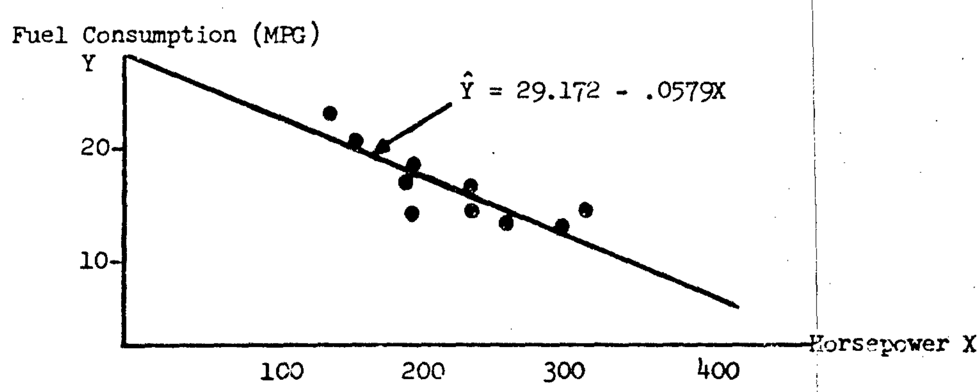

Fig. 28 —Regression Line Fuel Consumption vs Horsepower

Table 16

Hypothetical Data--Fuel Consumption vs Horsepower

Observation Number	Fuel Consumption (Y) mpg	Horsepower (X)	Y^2	X^2	XY
1	20	180	400	32,400	3600
2	22	150	484	22,500	3300
3	15	250	225	62,500	3750
4	10	350	100	122,500	3500
5	12	300	144	90,000	3600
6	10	325	100	105,625	3250
7	18	220	324	48,400	3960
8	16	210	256	44,100	3360
9	14	200	196	40,000	2800
10	12	280	144	78,400	3360
$\sum$	149	2,465	2,373	646,425	34,480

Statistical tests are available for determining whether or not the estimates of $\hat{A}$ and $\hat{B}$ are credible hypotheses for representing the true values of the population. In general, the credibility is dependent upon the variance of the estimates for $\hat{A}$ and $\hat{B}$. The test of hypothesis will be the subject of discussion in the next section on Significance Testing.

CITED REFERENCES

1. Bryant, Edward C., Statistical Analysis, McGraw-Hill, New York, 1966.

2. Draper, N. R., and Smith, N., Applied Regression Analyses, John Wiley & Sons, Inc., New York, 1968.

3. Johnston, J., Econometric Methods, McGraw-Hill, New York, 1960.

4. Stament, Alfred D., and Carl R. Wilbourn, Cost Estimating Relationships: A Manual for the Army Materiel Command," RAC-TP-449, Research Analysis Corporation, May 1972.

C.3 SIGNIFICANCE TESTING

DEFINITION

The term significance testing or test of hypothesis is used in statistics to mean the process of setting a rule by which an assumption about the population being sampled is either accepted or rejected.

DESCRIPTION

The assumption about the population is called the null hypothesis and is expressed as H_0. For example, if we hypothesize that the true mean μ of the population is equal to 10 or less, then the null hypothesis is written as

$$H_0 : \mu \le 10 .$$

The test of this hypothesis is simply a rule by which the researcher either accepts or rejects the hypothesis that it is the true value. The rule is based on the sample statistics which are called test statistics. For example, the rule might be to reject H_0 if the sample mean has a value larger than 11. The range of values of the sample mean for which the hypothesis is rejected is called the critical region or the significance region and is represented by the Greek letter α.

These concepts are illustrated in Fig. 29.

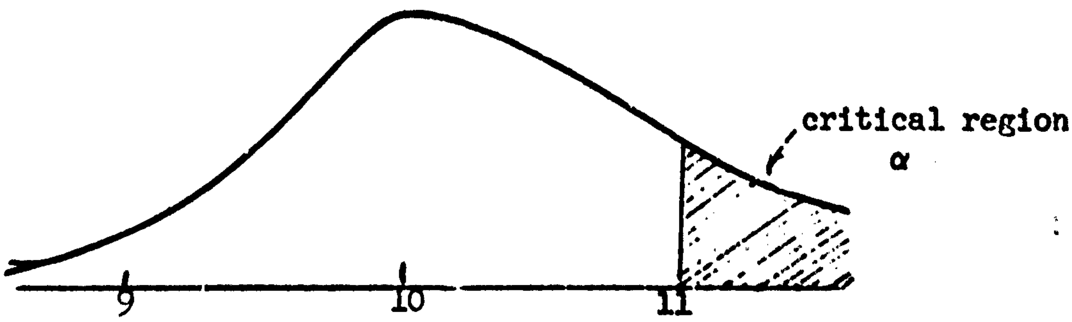

Fig. 2·—Hypothetical Distribution

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Thus, in our sample if we were to obtain a mean of 11 or larger we would reject the null hypothesis that the true mean is 10 or less. If the hypothesis is really true and we reject it, then a Type I error is committed. If the hypothesis is really false and we accept it, then a Type II error is committed. The type I error is represented by the critical region α.

How do we establish the critical region? The critical region is usually established by stating a level of risk the researcher is willing to assume. For example, he may say that he is willing to assume a 5% risk that he will reject the hypothesis when in fact, it is true. Then, the level of risk is translated to a value in the same dimensions as the null hypothesis by making a statement to the effect, "If the true mean is $H_o : \mu = 10$ and the true variance is $\hat{\sigma}^2 = \sigma^2$, at what point do I reject the hypothesis." In statistical notation this expression is given as

$$P(\mu \geq ? \mid H_o : \mu = 10, \hat{\sigma}^2 = \sigma^2) = .05$$

Tables are available for making these conversions.

The steps to be followed in hypothesis testing are:

1. Establish the null hypothesis and an alternative, e.g., Null Hypothesis $H_o : \mu \leq 10$
   Alternative Hypothesis $H_o : \mu > 10$.
2. Select the significance level of the test, e.g. $\alpha = .05$.
3. Convert the critical region to dimensions which are consistent with the null hypothesis, e.g., $\alpha = .05$ at 11.
4. Take sample and accept or reject null hypothesis on the basis of results.

APPLICATION

The example cited in the previous section relating fuel consumption to horsepower, will be used to illustrate the test of hypothesis on the regression coefficient $\hat{B}$. The slope of the line is given as -.0579

and we want to test to determine if the slope is significantly different from zero.

The null hypothesis is

$$H_o : B = 0$$
$$H_a : B \neq 0$$

We state that we are willing to be wrong 5 percent of the time in rejecting the null hypothesis when it is in fact true. Thus $\alpha = .05$.

Next we have to convert $\alpha = .05$ to the same dimensions as B. This can be accomplished by using the following formula.

$$B - tS_B \leq \hat{B} \leq B + tS_B$$

where $\hat{B}$ is the regression estimate of B

$S_{\hat{B}}$ is the square root of the variance of $\hat{B}$ or the standard deviation of $\hat{B}$

t is the number of standard normal deviates associated with $\alpha = .05$. This value may be obtained from any table listing the Students' t - Distribution (see References).

The formula for the standard deviation of the regression coefficent $\hat{B}$ is given by

$$S_{\hat{B}} = \frac{S}{\sqrt{\sum_{i=1}^{n} X_i^2 - \frac{(\sum_{i=1}^{n} X_i)^2}{n}}}$$

where

$$S = \sqrt{\frac{\sum_{i=1}^{n} Y_i^2 - \hat{A}\sum_{i=1}^{n} Y_i - \hat{B}\sum_{i=1}^{n} X_i Y_i}{n - 2}}$$

Substituting the values from Table .

$$S = \sqrt{\frac{2373 - 4346.628 + 1996.39}{8}}$$

$$= \sqrt{2.84}$$

$$= 1.685$$

$$S_{\hat{B}} = \frac{1.685}{38,802}$$

$$= .000043$$

t = 2.306 from the table of percentage points of Students' t - Distribution.

$$0 - (2.306)(.00043) \le \hat{B} \le 0 + (2.306)(.000043)$$

$$-.0001 \le \hat{B} \le .0001$$

Figure 30 illustrates the critical regions for this test of hypothesis.

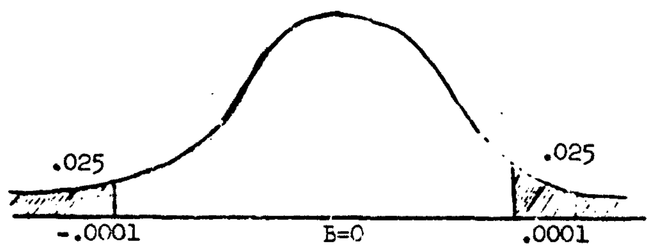


Fig. 30—Hypothetical Critical Regions

The sample value for $\hat{B}$ = -.0579 lies to the left of the critical point of -.0001, and therefore the hypothesis is rejected that the slope is 0. Other tests could have been made such as is the slope less than -.03 or is the slope greater than -.1.

REFERENCES

1. Hadley, G., Introduction to Probability and Statistical Decision Theory, Holden-Day, San Francisco, 1967.

2. Hicks, Charles R., Fundamental Concepts in the Design of Experiments, Holt, Rinehart, and Winston, New York, 1964.

3. Johnson, Norman L. and Leone, Fred C., Statistics and Experimental Design, Vol. I, John Wiley & Sons, Inc., New York 1964.

4. Mode, Elmer B., Elements of Statistics, Prentice-Hall, Englewood Cliffs, New Jersey, 1961.

5. Stament, Alfred D. and Carl R. Wilburn, Cost Estimating Relationships: A Manual for the Army Materiel Command, RAC-TP-449 Research Analysis Corporation, May 1972.

Appendix D

OTHER TECHNIQUES

D.1 DECISION LOGIC TABLE

PURPOSE

A decision logic table (DLT) is a device for summarizing sequential conditional relations among classes or events. These may take a simple form of "if A then B" or a more complex form such as "if A and if B then C and then D." A DLT provides a method of compacting ordinary textual presentation into tabular narrative. The tabular format facilitates the location of pertinent information.

DESCRIPTION

A DLT contains conditions (the if's), actions (the then's), and rules, each rule representing a unique combination of condition(s) and action(s). Although there are basic DLT styles and variants, the construction of any DLT requires:

a. Defining the purpose of the table
b. Identifying the relevant conditions
c. Listing the actions to be followed for all sequential condition patterns.

The previous paragraph is based primarily on material from the Air Force SA/OR Compendium[1] (pp 71-72). Table 17 provides a concrete example of a DLT.

HEADER

Table 17

Table Header: DECISION LOGIC TABLE

Table Number → TABLE 3-1

Table Name → STEPS IN APPROVING OR DISAPPROVING AN ORDER

Labels	RULE	A	B	C	D
Stub Header →		A	B	C	D
		(condition stubs)			(action stub)
Rule Header →	RULE	If credit limit is	and if pay experience is	and if special clearance has been obtained	then
		(condition entries)			(action entries)
	1	okay			approve order
	2	questionable	favorable		approve order
Rules →	3	not favorable	not favorable	yes	approve order
	4	not favorable	not favorable	no	return to sales department

BODY

NOTES: (if any)

Table 17 and supplementary definitions required for its proper interpretation are based on DA PAM 310-11[2] (pp 2-3). The definitions, exemplified by references to the sample DLT follow:

a. A stub header is a letter identifier that bears a one-to-one correspondence with a narrative condition stub or action stub. The letter identifier provides a quick and accurate shorthand reference for either written or oral communication. In Table 17 B represents "and if pay experience is" while D represents "then".

b. A condition entry constitutes one of the relevant alternatives under a condition stub. In Table 17 "questionable" is the second condition entry under "If credit limit is".

c. An action entry constitutes one of the relevant actions under an action stub. In Table 17 "return to sales department" is the fourth action alternative (some of which are duplicates) under "then".

d. A rule header is a numeric identifier that bears a one-to-one correspondence with a unique sequence of conditions and action(s), i.e., rule. In Table 17 rule 3 is that "if the credit limit is not favorable, the pay experience not favorable, but special clearance has been obtained, then the order should be approved." For patent reasons, use of numbers for rules in place of narrative descriptions eases communication.

APPLICATION

The RAC Cost Factors Manual[3] (pp 5-6 to 5-8) describes a standard Governmental system for the pricing of contractor data. Pricing of data is comparable to that of hardware in that both may be subject to analysis, justification of estimate, and negotiation. The manual describes the system by text and non-DLT table. Table 18 provides an example of a DLT with comparable information.

Table 18

DATA COST GROUPS

	A	B	C	D
Rule	Is data essential to performance of contract?	Does submitted data involve substantial rework?	Are costs of producing, handling and delivery significant?	Then
1	No			Price estimate required with cost breakdown and description of method.
2	Yes	Yes		Price estimate required with cost breakdown and description of method.
3	Yes	No	Yes	Price estimate required with description of method.
4	Yes	No	No	No charge to Government.

LIMITATIONS

Decision processes can be described narratively, in DLTs, tree diagrams, and flow diagrams. Because of greater familiarity, many readers may find text or text supplemented by non-DLT tables clearer than DLTs. The analyst should therefore use DLTs with caution for final documentation purposes. The paragraph below (Ref 2, p 1) describes narratively the information provided in Table 17.

> If a customer's credit limit is acceptable, then the order may be approved. If the credit limit is questionable but the customer's pay experience is favorable, then the order may be approved. If, on the other hand, the credit limit is not favorable, the order may be approved only if a special clearance has been obtained. Lastly, if the credit limit is not favorable and the pay experience is

not favorable, and if no special clearance has been obtained, then the order should be returned to the sales department.

In certain applications flow diagrams will be found superior to DLTs. This is especially likely to be the case where feedback capability exists.

CITED REFERENCES

1. Robert E. Schmaltz, United States Air Force Assistant Chief of Staff, Studies and Analysis, "A Compendium of Systems Analysis/Operations Research Methodology," Vol I, 15 Jul 68.

2. Dept of Army, "The Decision Logic Table Technique," PAM 310-11, May 67.

3. Doris C. Berger, John O'Flaherty, and Joseph String, Jr., "Selected Uniform Cost Factors: A Manual for the Army Materiel Command," RAC-TP-451, Research Analysis Corporation, Jun 72.

D.2 DELPHI METHOD

PURPOSE

The Delphi method or Delphi technique is a subjective scaling technique that can be used to obtain a concensus from a group of professionals or experts on questions which are cloaked in uncertainty and which cannot be directly measured or evaluated. It provides a means for the nonspecialist to obtain "best opinion" information from a number of experts who, through controlled information, arrive at a concensus.

DESCRIPTION

Individual experts are asked to respond to questions. Their answers and the reasons for them are given to all other participating experts who are again interrogated. This process of question and requestion--after being given new, refined feedback--continues until progress toward a consensus appears negligible. Reasons for highly divergent viewpoints are documented to minimize overlooking any aspects of the question. The entire Delphi process may take a long period of time to develop the questions, communicate them to the respondents, get them back, evaluate the results and go through the cycle again. While normally used for larger, policy issues, such as forecasting requirements for the future, it also can be applied to more detailed problems. The following examples describe the technique and its use.

APPLICATIONS

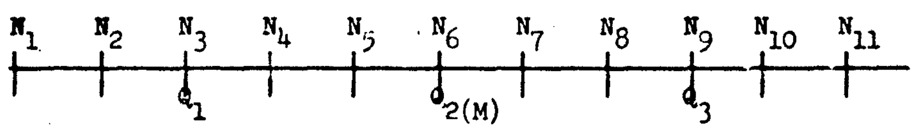
Two sample applications are provided which demonstrate the applicability of the method. The first is a modification of an example from Quade's RAND report

(Ref 1) which illustrates the detailed technique of a specific problem. The second example shows a broader and more often used context of application.

<u>Example 1</u>

Assume there is a need to derive an estimate of the overall benefit that would be derived from selecting a particular type of vehicle. For example, the estimate desired might be a particular number, N, that would represent a dollar valuation or savings. The procedure to be followed would be:

First, each expert is asked to give an independent estimate of N. The responses would be arranged in order of magnitude and divided into four equal areas with quartile points Q_1, Q_2, and Q_3, with Q_2 being the median. The responses might appear as follows (assuming there were 11 participants):



Second, each respondent is asked to reconsider his previous answer in view of the Q_1, Q_2, and Q_3 values. Those who had answers outside the Q_1 or Q_3 range, either in the original response or who have a revised response outside the range, are asked to state why the answer should be lower or higher than the majority opinion stated in the first round.

Third, the results of the second round (normally less dispersed than the first) are communicated to the experts in the same way, along with the reasons given for raising or lowering the values. The experts are asked to review the new answers (with a new interquartile range) and the arguments for those outside the range, and are given an opportunity to revise their previous estimates. If any respondent's revised estimate falls outside the second round's range, he is asked to explain his decision.

Finally, the quartiles of the third round's distribution and the counterarguments are given to all the respondents and one last revision solicited. The median of round 4 is considered to be the group position as to what the number should be.

Example 2

The Delphi technique was applied to the question, "What logistics units, skills, and material should the peacetime Army contain during the 1975 to 1985 period to perform its initial wartime missions and also to provide a base for rapid expansion to meet subsequent support requirements?" (Ref 5). A series of questionnaires were sent to selected groups of individuals in two major phases: the first, a trial run to prove the problem and test the value of the method, and the second, a full-scale Delphi experiment. The experiment caused a reordering, some revision, and some substitution of questions which, as a final questionnaire was sent to 31 "experts." These experts had broad backgrounds in military planning with a mix of tactical, strategic and logistics experience.

After each iteration, responses to questions were compiled, summarized and plotted on a quartile scale. The results (both opinions and reasons) were made available to all respondents.

It took only 3 iterations to converge on answers to all problems. The percent change in the median answer from the median of the previous iteration was found to be 12.6 between the first and second iterations and 3.3 between the second and third. The mean percent variance around the median was calculated for the 35 questions to be 78.0 in the first, 48.5 in the second and 5.0 in the third using the mean difference as equal to $\frac{1}{2}$ times (3rd quartile value minus the 1st quartile value) divided by the median value times 100.

Other applications can be made in technological assessment areas such as the probable affect of the institution of the metric system on the military establishment, what an Army officer can be expected to "look like" in the 1980's for establishing curricula at West Point, and to even more definitive problems as outlined in the RAND example.

LIMITATIONS

The Delphi technique is a method of eleciting information from expert individuals and a better-than-nothing means of assigning a quantitative value to subjective opinion. If handled properly it can provide objectivity to a problem, but it lends itself to a myriad of misuses, depending on the standards of the individuals or groups conducting the exercise. Since it can take a long period of time to develop the questions in the proper form and go through the process, it is often short-circuited by a panel discussion or a brain-storming session, either of which obviate the objective value of the technique.

Although a case can be made for a group having more total expertise than any individual member, the opinion of a real expert in a particular area may be diluted. The output of any Delphi exercise is, at best, an opinion, and even though it may be better than some other method, this limitation must be kept in mind.

REFERENCES

1. E.S. Quade and W. I. Boucher, "Systems Analysis and Policy Planning: Applications in Defense," a report prepared for the United States Air Force Project, RAND (R-439-PR, abridged), June 1968.

2. N.C. Dalke, "The Delphi Method: An Experimental Study of Group Opinion," The RAND Corporation, RM-5888-PR (1969).

3. O. Helmer, "Convergence of Expert Consensus Through Feedback" The RAND Corporation, P-2973 (1954).

4. M.I. Taft and A. Reisman, "Computer Time-Saving Applications in Economic Analysis: An Integrated Approach," Department of Operations Research, Case Western Reserve University, T.M. 151 (1969).

5. Albert D. Tholen, Louis C. Peltier, Thomas F. Ferrara, and John T. Sincavage, "A Forecast of Logistics Requirements, Application of the Delphi Method to the Study of Peacetime Army Logistic Base," The Research Analysis Corporation, RAC-TP-427 (1971).

D.3 FLOW DIAGRAM

PURPOSE

A flow diagram is a graphical technique used to portray the order of major operations in a process or problem solution. Flow diagrams are used by programmers to block out major steps prior to coding and as part of the documentation package prepared for turnover of computer programs.

Flow diagrams are also used in noncomputer applications to assist in problem formulation and documentation. Frequently a flow diagram is used to graphically outline a series of sequential steps. This is generally followed by verbal descriptions of the content of each of the steps and the relationships among them.

DESCRIPTION

All flow diagrams describe and sequentially link operations. In simple diagrams each operation is represented by a terse verbal description enclosed within a rectangular box. Lines and arrows are used to indicate orders of occurrence among the operations. To facilitate diagram use and comprehension, particularly for complex applications, nonrectangular symbols are often used in lieu of boxes to represent special operations (input/output, decisions, start and stop, etc.)

Conventional flow diagram symbols are presented elsewhere in this appendix, see "Computer Terms/Symbols." Figure 31 depicts a report completion flow diagram that uses a special decision operation symbol in addition to the standard boxes and arrows. The figure is typical in that the described operations are general and could easily be broken down into numerous suboperations.

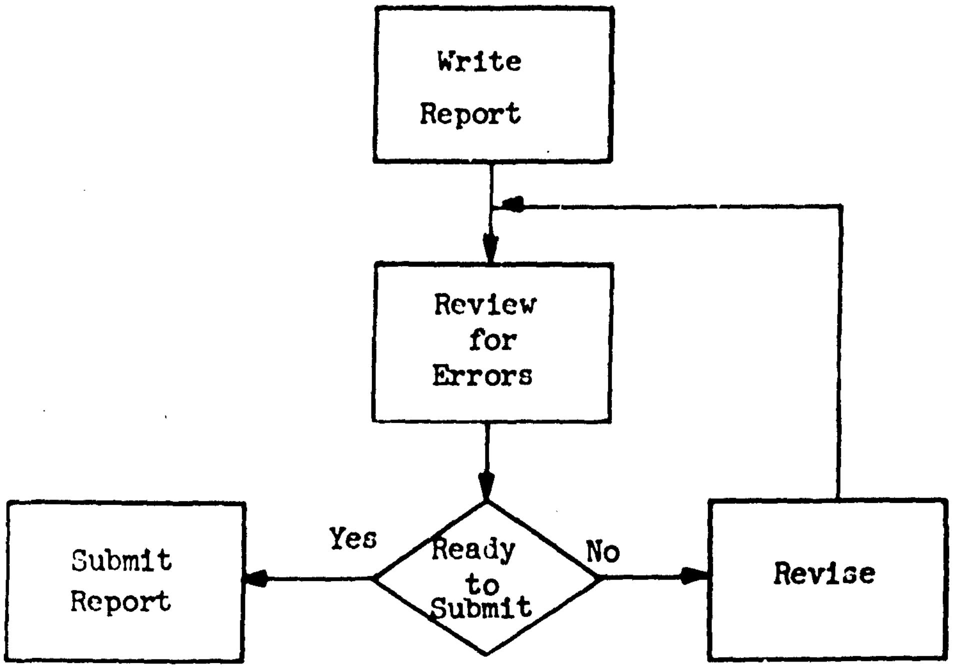


Fig. 31—Completing a Report Assignment

APPLICATIONS

Economic Analysis Process

Figure 32 is reproduced from the Air Force Economic Analysis Handbook[1] (p 4). It provides the background for discussing the process of economic analysis and is stressed as the one essential for all readers to absorb. The left-hand side of Fig. 2.1 in Vol I of the present report provides an alternative view—generally less detailed but with more emphasis on study planning.

Getting the Officer to Work

Figure 33 in this section has been compressed from one used in an Army ADPS orientation guide.[2] Introductory descriptive material has been reproduced in full from the guide and follows:

> An ADPS computer uses a simple "on" or "off" condition to make a decision at each stage of a process, based upon previously programmed criteria. It is similar to the "imposing" series of automatic command decisions required of an officer on his way to work in the morning before he is fully awake.

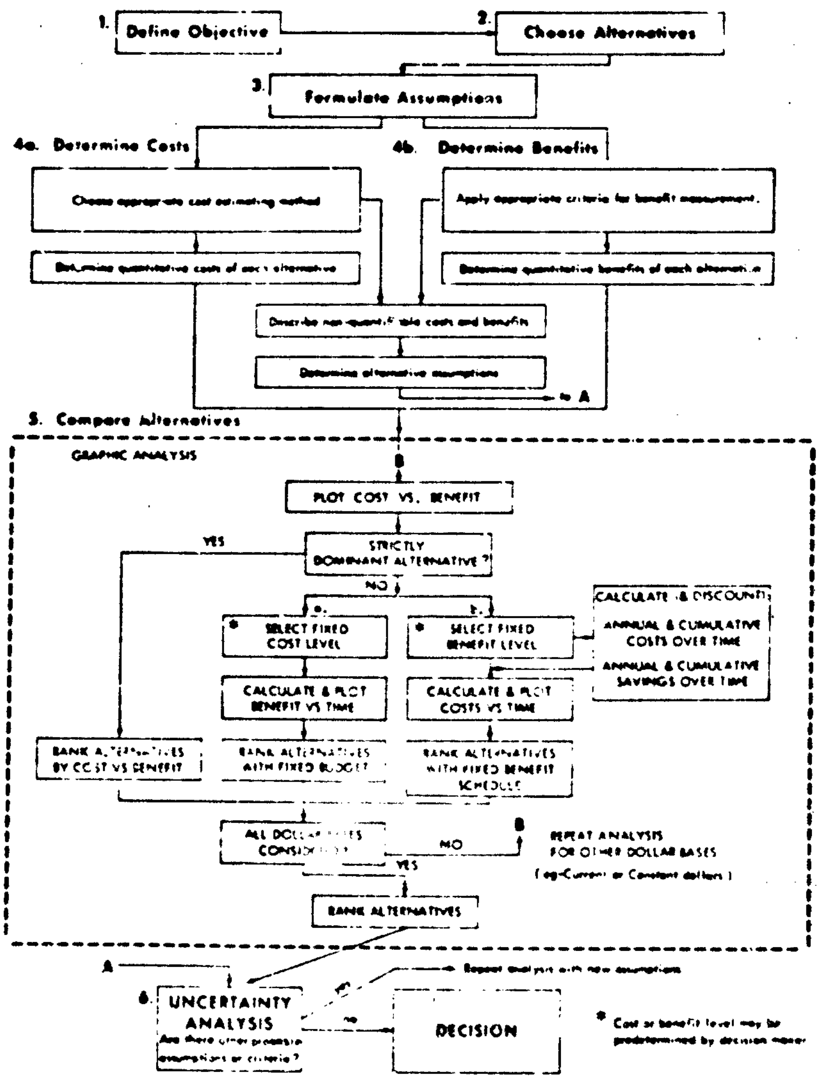


Fig. 32 — Economic Analysis

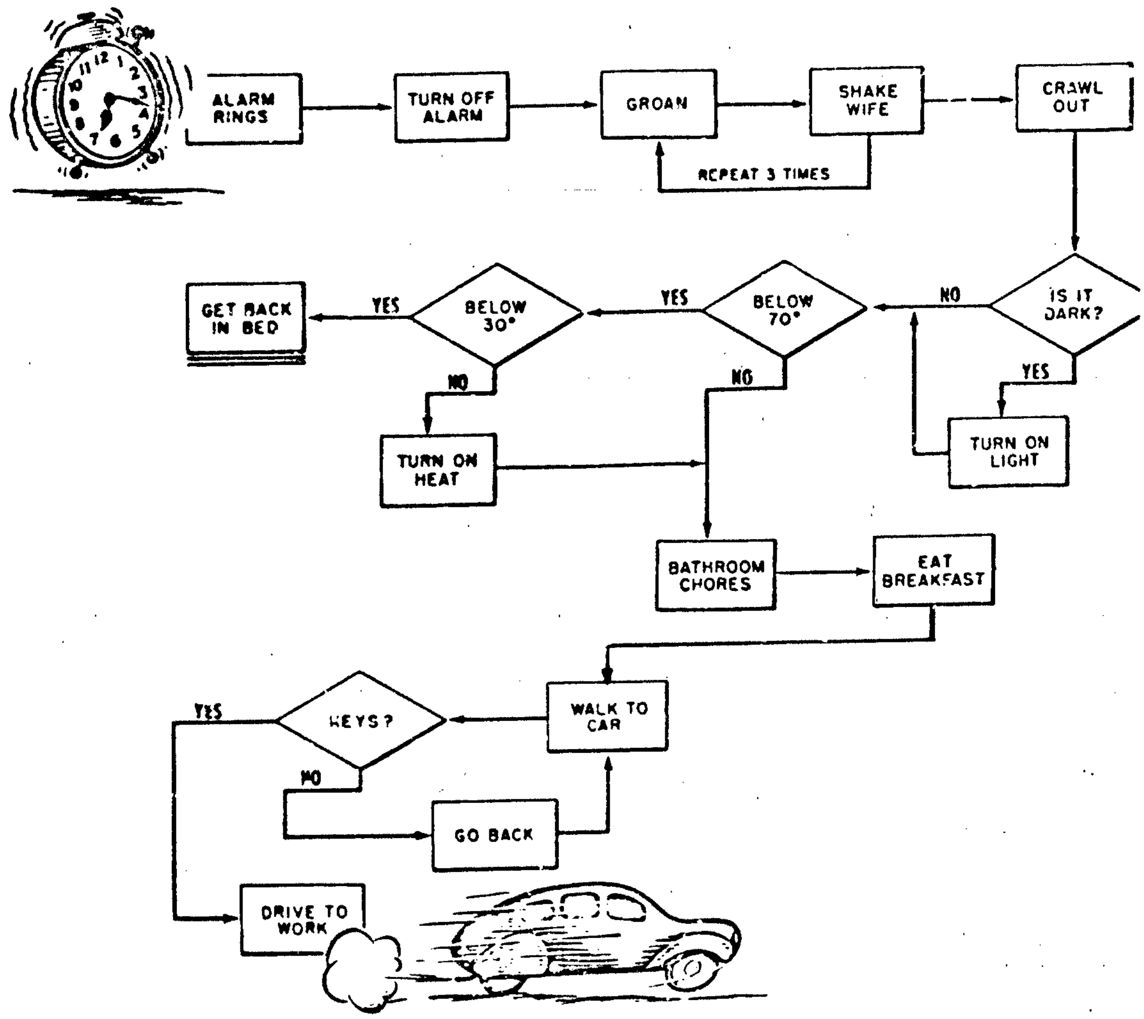


Fig. 33 —Reporting for Duty

LIMITATIONS

A flow diagram is an essential tool to the computer programmer, serving a purpose analogous to an outline for a writer. As in the case of outlines, it should be recognized that computer flow diagrams are usually considerably more meaningful to the preparer than to any intended audience.

Flow diagrams highlight relationships. When used for illustration purposes in noncomputer applications, the diagrams usually should be followed by verbal descriptions to avert oversimplification. Sometimes the information meant to be conveyed by the diagram can be more clearly and economically presented by use of a decision logic table or tree diagram.

Flow diagrams should, of course, be used only to improve communication, never for purposes of decoration. To the extent possible their use should be tempered by what is known about the intended audience.

CITED REFERENCES

1. Dept of Air Force, Office of the Comptroller, "Economic Analysis Handbook," 2d edition, undated.

2. US Army Signal School, "Introduction to Automatic Data Processing Systems," 15 January 1960.

OTHER REFERENCES

1. Edward Mack McCormick, Digital Computer Primer, McGraw-Hill Book Company, Inc., New York, 1959.

2. Theodore G. Scott, Basic Computer Programming, Doubleday & Company, Inc., Garden City, New York, 1962.

D. 4 SIMULATION

PURPOSE

Simulations are used to approximate, represent, or express planning situations or problems in a form suitable for study much as a model airfoil in a wind tunnel is used to simulate the effects of air currents on flight. Normally used in a planning or forecasting role, simulation helps decisionmakers understand input requirements and alternative solutions to problems without undergoing the necessary time and monetary expenses of adopting a plan, implementing it, evaluating it in operation, making adjustments, evaluating again, and so on until a desired result is achieved.

Simulation models allow various factors to be tested, manipulated, tested again, and results expressed for evaluation of the consequences of action taken. Appropriate action based on the modeled results can then be instituted in the "real life" situation. The setting up of the simulation can often prove as valuable as the results achieved because of the requirement to examine the intricacies and correlations of a situation in minute detail. Computers are often used to aid the simulation because of the large numbers of factors, the complexity of those factors, and their interrelations.

DESCRIPTION

Much like the airfoil in the wind tunnel, an office or factory can be laid out on a drawing and templates used to investigate alternative layouts for maximum efficiency of production line flow within allocated space, for example. Simulation or modeling of an environment is also used in the laying out and manipulation of organizational relations, concepts, ideas, flows of people or things, and inventory control. It can be used

to answer the "What would happen if..." questions that analysts and managers ask in managing and planning their operations. The solutions to these questions normally take the form of:

1. Preparing the model
2. Testing the model and comparing its behavior with the actual situation.
3. Making appropriate changes.
4. Rerunning the model.
5. Analyzing the results.
6. Repeating the above steps for alternative solutions.
7. Selecting desirable solutions.
8. Acting on the model solution in the real life situation.

Included in most planning simulations are the elements of transportation or movement within a system (trucks, aircraft, production or manufacturing flows, people flows, inventory flows, data flow through a computer, etc.), facilities and storage points in that system (garages, hangers, loading docks, terminals, warehouses, classrooms, packaging points, manufactoring points, computer buffer areas, etc.), waiting lines or queues, and time (transit time, facility or storage time, waiting time, service time, etc.). Many operations research and statistical techniques can be used in representing or helping to represent the problems to be simulated, but are not necessary for a simulation.

A special simulation technique termed Monte Carlo is used to solve deterministic problems of real situations too expensive or too complex to solve analytically. A stochastic analog to the problem at hand is used to estimate the solution. Probability and random number generators used in sampling situations are integral to Monte Carlo. See the reference list for sources for further description.

APPLICATIONS

A commander may ask his plans office to investigate alternative uses of a large hanger being made available with the transfer of a helicopter unit. The alternatives that may be considered are:

1. A consolidated vehicle maintenance facility
2. A consolidated Post Exchange and Concession facility

3. A billeting facility for enlisted men

4. A warehouse for supplies

Part of the economic analysis of each alternative may include a proposed layout of respective configurations for analysis of floor space and establishment of a base-line for analysis of modification costs.

Another application could be the simulation of the Army Training Establishment. Using high speed computers, a model would provide projected 3-year training schedules for each course offered. These schedules would detail numbers of students projected for input into each course, those projected to be in training, those expected to drop out, and those projected to graduate. This could be done for each type of trainee. Costs per graduate and trainer, instructor, and overhead requirements per course could also be provided. This model would allow modifications of priorities of courses, preferences for locations for training, class capacities, and attrition rates. It would enable the Army to more effectively plan its training programs to meet the changing needs of the Army at the least cost in terms of both manpower and funding requirements. A model of this general description is under development by the General Research Corporation for the DCS personnel, Department of the Army.

The Monte Carlo technique of simulation can be applied to the quantification of uncertainty inherent in the projection of weapon system costs and in processes involving multiple channel queues. This would require both the expression of input estimates in terms of probability distributions and cost equations pertinent to the particular model, say a missile production model. The Monte Carlo simulation approach would then generate the frequency distribution for system cost and statistical measures to illustrate the nature and measure of the uncertainty involved in the system cost. By knowing an average rate of arrival of parts and average distribution of service times, random numbers could be used to generate simulated arrivals and production times from the known distributors. The whole procedure would consist of estimating the distribution for the total process based on detailed knowledge of the behavior of the components.

LIMITATIONS

A simulation model is only as good as its representation of the real world. Simulation involves many variables and many parameters leading to a great deal of complexity. While it can give answers to difficult questions, it should be recognized as a last resort. Should a direct analytic solution be available, it should be used, but when it is not (whether because of time, cost, or other reason), simulation can provide a feasible approach.

REFERENCES

1. John E. Cremeans, "Why Simulation?", Research Analysis Corporation, McLean, Virginia, (RAC P-30), August 1967.

2. Donald F. Schaefer, Frank J. Husic and Michael F. Gutkowski, "A Monte Carlo Simulation Approach to Cost-Uncertainty Analysis," Research Analysis Corporation, McLean, Virginia, (RAC-TP-349), March 1969.

3. Brent L. Bowen, et al, "Student Instructor Load Model - Phase II (SILII), Summary Description," Research Analysis Corporation, (RAC-TP-458), December 1972.

D.5 TREE DIAGRAM

PURPOSE

A tree diagram is a flexible graphical technique for portraying relations among classes or events. A tree diagram can be used, for example, to illustrate a hierarchical structure or to enumerate the probabilities of sequential events. A tree diagram can be useful in problem formulation and/or documentation of results.

DESCRIPTION

Tree diagrams contain sequential branches. The number of branches that originate at each branch point represents the number of subclasses (hierarchy) or possible outcomes (probability). A tree diagram reads from left to right and always includes at least two branches. Figure 34 depicts division into two branches, followed by division of each branch into three additional branches.

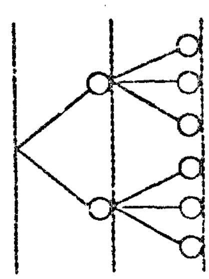


Fig. 34—Example of a Tree Diagram

APPLICATIONS

Probability

Figure 35 illustrates the array of probabilities for two successive draws of marbles (three white and two black) from a bag without replacement

of marbles between draws. The uppermost branch in the figure will be followed through for purposes of exemplification.

The probability of drawing a white marble at the first draw—P(W)—is simply equal to the ratio of white marbles to total marbles (3/5 or .6). Since the first marble is not replaced, the probability of a white marble on the second draw is .5 (2/4). The probability of two successive draws of white marbles—P(W,W)—is equal to the product of the cited probabilities (.6 x .5 = .3). This is a result of one of the basic laws of probability. The "Probability" section presents and illustrates these laws. The five-marble example of this section provides some of the illustrations.

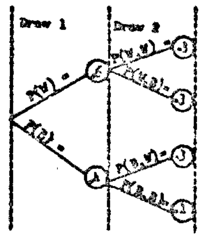


Fig. 35—Probabilities - Tree Diagrams

Figure 35 illustrates two characteristics that are true of every probabilistic tree. First, the sum of the probabilities of all branches is equal to 1.0 as long as all are of uniform length (i.e., traverse an equal number of branch points). Thus, at the first marble draw .6 + .4 = 1.0, and for two successive draws .3 + .3 + .3 + .1 = 1.0. The second characteristic, which is actually a corollary of the first, is that the sum of the probabilities of all branches from a given branch point is equal to the parent branch probability, e.g., .3 + .3 = .6 and .3 + .1 = .4.

Hierarchy

Figure 36 is reproduced from RAC-TP-451[1] (Chap 6). The diagram was used to introduce a set of cost elements and equations for use in estimating direct personnel costs (training, pay and allowances) for Army weapon systems. The diagram "presents the general scheme of the [personnel cost] model. Columns 1 to 7 depict disaggregation of direct personnel into their relevant functions and cost-generating activities.

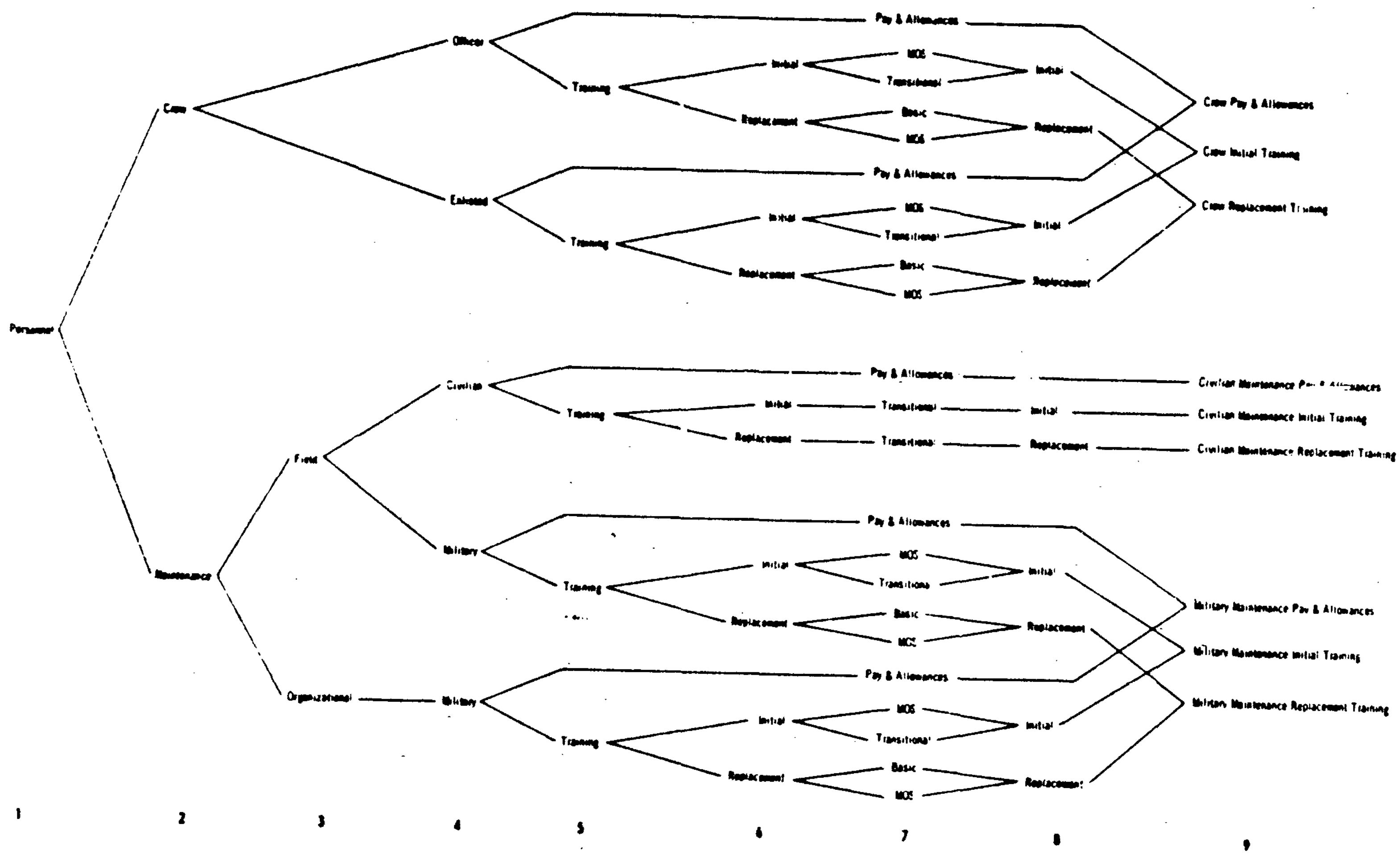


Fig. 36—General Scheme of the Personnel Model

Costs of each element shown in Col 7 are explicitly estimated. Columns 8 and 9 display the reaggregation of elements into nine ... (categories of) direct personnel costs."[1]

LIMITATIONS

Trees are perhaps most useful in portraying processes where all possible final outcomes (classifications) are of interest and where the final outcomes are not designed in any way by operating on the intermediate outcomes (via feedback, for example). Processes that do not possess these characteristics can be more effectively described via decision logic tables or flow diagrams.

CITED REFERENCE

1. Doris C. Berger, John O'Flaherty, and Joseph String, Jr., "Selected Uniform Cost Factors: A Manual for the Army Materiel Command," RAC-TP-451, Research Analysis Corporation, Jun 72.

OTHER REFERENCES

1. Richard I. Levin and C. A. Kirkpatrick, Quantitative Approaches to Management, McGraw-Hill Book Co., New York, 1965.

2. Robert E. Schmaltz, United States Air Force Assistant Chief of Staff, Studies and Analysis, "A Compendium of Systems Analysis/Operations Research Methodology," Vol I 15 Jul 68.